Journal
of
The Franklin Institute

EDITOR, HENRY BUTLER ALLEN, MET.E., D.SC.

ACTING ASSISTANT EDITOR, JOHN FRAZER, PH.D.

Associate Editors:

JOSEPH S. AMES, PH.D.
WILDER D. BANCROFT, PH.D.
C. B. BAZZONI, PH.D.
E. G. COKER, F.R.S.
ARTHUR L. DAY, SC.D.
R. EKSERGIAN, PH.D.
A. S. EVE, F.R.S.
PAUL D. FOOTE, PH.D.
W. J. HUMPHREYS, PH.D.
C. E. K. MEES, D.SC.
WILLIAM B. MELDRUM, PH.D.
HENRY C. SHERMAN, SC.D.
W. F. G. SWANN, D.SC.
HUGH S. TAYLOR, D.SC.
A. F. ZAHM, PH.D.
JOHN ZELENY, PH.D.

Committee on Publications:

G. H. CLAMER, CHAIRMAN
RICHARD HOWSON
C. L. JORDAN
LIONEL F. LEVY
MALCOLM LLOYD, JR.
HIRAM S. LUKENS
RICHARD H. OPPERMANN
WINTHROP R. WRIGHT

Vol. 235 **APRIL, 1943** **No. 4**

CONTENTS

Theory of Suspension Bridges ..... STEPHEN P. TIMOSHENKO 327

The Quantitative Determination of Hypo in Photographic Prints with Silver Nitrate J. I. CRABTREE, G. T. EATON, AND L. E. MUEHLER 351

Contributions of Science to an Appreciation of Music ..... ABRAHAM PEPINSKY 361

The Story of the Bicycle ..... N. W. SAMPLE, JR., AND T. COULSON 393

Notes from the National Bureau of Standards 405

The Franklin Institute Notes 413

Notes from the Biochemical Research Foundation 416

Book Reviews 425

Publications Received 432

Current Topics 350, 412, 433

Entered as second-class matter March 14, 1928, at the post office at Lancaster, Pa., under act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

Published by

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

Prince and Lemon Streets, Lancaster, Penna., and

Benjamin Franklin Parkway at Twentieth St., Philadelphia, Penna.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

Indexes to the semi-annual volumes of the JOURNAL are published with the June and December numbers. The contents are also indexed in *The Industrial Arts Index*.

THE FRANKLIN INSTITUTE

OFFICERS FOR 1943

President	CHARLES S. REDDING
Vice-presidents	WALTON FORSTALL
	W. CHATTIN WETHERILL*
	SAMUEL S. FELS
	RICHARD W. LLOYD
	RICHARD T. NALLE
Secretary and Director	HENRY BUTLER ALLEN
Assistant Secretary	JOHN FRAZER
Treasurer	M. M. PRICE
Assistant Treasurer	RICHARD W. LLOYD
Manager of Operations	WILLIAM F. JACKSON, JR.
Controller	SAMUEL J. CLEVENGER, JR.
Librarian	WALTER A. R. PERTUCH

BOARD OF MANAGERS

HENRY BUTLER ALLEN
EDWARD G. BUDD
G. H. CLAMER
IRENEE DUPONT
SAMUEL S. FELS
WALTON FORSTALL
W. H. FULWEILER
NATHAN HAYWARD
L. H. HENDRIXSON
JOSEPH S. HEPBURN
CLARENCE L. JORDAN
CONRAD N. LAUER
LIONEL F. LEVY
HORACE P. LIVERSIDGE
MALCOLM LLOYD, JR.
RICHARD W. LLOYD
HIRAM S. LUKENS
ORUS J. MATTHEWS
MARSHALL S. MORGAN
RICHARD T. NALLE
CHARLES PENROSE
GEORGE WHARTON PEPPER
M. M. PRICE
CHARLES S. REDDING
JAMES H. ROBINS
JAMES S. ROGERS
PHILIP C. STAPLES
CLARENCE TOLAN, JR.
PHILIP H. WARD, JR.
EDWARD WARWICK
W. CHATTIN WETHERILL*
D. ROBERT YARNALL

COMMITTEES OF THE BOARD OF MANAGERS

Executive Committee	G. H. CLAMER, *Chairman*
Hostess Committee	MRS. JOHN WHITE GEARY, *Chairman*
Vermilye Medal Committee	PHILIP C. STAPLES, *Chairman*

COMMITTEES OF THE INSTITUTE

Bartol Research Foundation Committee	NATHAN HAYWARD, *Chairman*
Biochemical Research Foundation Committee	RICHARD T. NALLE, *Chairman*
Committee on Science and the Arts	JOSEPH S. HEPBURN, *Chairman*
Endowment Committee	
Finance Committee	MARSHALL S. MORGAN, *Chairman*
Library Committee	L. H. HENDRIXSON, *Chairman*
Meetings Committee	W. H. FULWEILER, *Chairman*
Membership Committee	MORTON GIBBONS-NEFF, *Chairman*
Memorial and Museum Committee	CLARENCE L. JORDAN, *Chairman*
Publications Committee	G. H. CLAMER, *Chairman*

*Is in the Armed Service of the United States.

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 235 APRIL, 1943 No. 4

THEORY OF SUSPENSION BRIDGES

BY

STEPHEN P. TIMOSHENKO

Professor of Theoretical and Applied Mechanics, Stanford University, California.

PART II.

5. APPLICATION OF TRIGONOMETRIC SERIES IN CALCULATING DEFLECTIONS.

The deflection curve of a stiffening truss can be obtained also by using trigonometric series.* In applying this method not only the calculation of deflections is simplified but also the calculation of H_p can be made with better accuracy since, without much complication, we can use equation (16) instead of the simplified equation (17) used in the preceding article. Let us begin with the case of one concentrated force acting on the stiffening truss, Fig. 6. The differential equation (21) in this case becomes

$$EI\frac{d^2\eta}{dx^2}-(H_w+H_p)\eta=H_p\frac{4f}{l^2}x(l-x)-\frac{Pcx}{l},$$

$$\text{for}\quad x<(l-c),\quad (a)$$

and

$$EI\frac{d^2\eta}{dx^2}-(H_w+H_p)\eta=H_p\frac{4f}{l^2}x(l-x)-\frac{P(l-c)(l-x)}{l},$$

$$\text{for}\quad x>(l-c).\quad (b)$$

* See writer's paper in Transactions Am. Soc. C. E., Vol. 94, p. 377, 1930.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

The right sides of these equations can be represented for the entire length l of the truss by the trigonometric series

$$b_1 \sin\frac{\pi x}{l} + b_2 \sin\frac{2\pi x}{l} + b_3 \sin\frac{3\pi x}{l} + \cdots \qquad (c)$$

the coefficients $b_1, b_2, b_3, \cdots$ of which must be calculated in the usual way from the formula

$$b_m = \frac{2}{l}\left\{ H_p \frac{4f}{l^2}\int_0^l x(l-x)\sin\frac{m\pi x}{l}\,dx - \frac{Pc}{l}\int_0^{l-c} x\sin\frac{m\pi x}{l}\,dx - \frac{P(l-c)}{l}\int_{l-c}^{l}(l-x)\sin\frac{m\pi x}{l}\,dx\right\},$$

which gives

$$b_m = \frac{16H_p f}{m^3\pi^3}(1-\cos m\pi) - \frac{2Pl}{m^2\pi^2}\sin\frac{m\pi(l-c)}{l}. \qquad (d)$$

Since series (c) is applicable for the entire length of the truss, the two equations (a) and (b) can now be replaced by one equation

$$EI\frac{d^2\eta}{dx^2} - (H_w + H_p)\eta = \sum_{m=1}^{\infty} b_m \sin\frac{m\pi x}{l}. \qquad (e)$$

The solution of this equation, satisfying the end conditions, will now be taken in the form of the series

$$\eta = \sum_{m=1}^{\infty} a_m \sin\frac{m\pi x}{l}. \qquad (f)$$

Substituting this series into equation (e) and equating, for each value of m, the coefficients of $\sin m\pi x/l$, we obtain

$$a_m = -\frac{b_m l^2}{EIm^2\pi^2 + (H_w + H_p)l^2}$$

and the series (f) becomes

$$\eta = -\sum_{m=1}^{\infty} \frac{b_m l^2 \sin\frac{m\pi x}{l}}{EI(m^2\pi^2 + k^2 l^2)},$$

where k^2, as before, denotes the value of the ratio $(H_w + H_p)/EI$. Substituting expression (d) for b_m, we finally represent

the deflection of the truss by the following series

$$\eta = -\frac{32H_p f l^2}{\pi^3 EI} \sum_{m=1,3,5,\ldots}^{\infty} \frac{\sin \frac{m\pi x}{l}}{m^3(m^2\pi^2 + k^2 l^2)} + \frac{2Pl^3}{EI\pi^2} \sum_{m=1,2,3,\ldots}^{\infty} \frac{1}{m^2(m^2\pi^2 + k^2 l^2)} \cdot \sin \frac{m\pi(l-c)}{l} \cdot \frac{\sin m\pi x}{l} \cdot \quad (32)$$

This is a rapidly converging series, and the calculation of deflections requires less time than in the case when we are using equations (27) to (29). Applying this series to the numerical example of the preceding article (Fig. 7*b*) we have

$$c = 0.75l, \quad H_p = 1.341P, \quad k^2 \approx H_w/EI, \quad kl = 10, \quad f = 0.1l$$

and series (32) gives the deflection curve:

$$\eta = -0.1384 \frac{Pl}{H_w}\left(0.9102 \sin \frac{\pi x}{l} + 0.0196 \sin \frac{3\pi x}{l} + 0.0023 \sin \frac{5\pi x}{l} + \cdots\right) + 0.2026 \frac{Pl}{H_w}\left(0.6434 \sin \frac{\pi x}{l} + 0.1793 \sin \frac{2\pi x}{l} + 0.0416 \sin \frac{3\pi x}{l} - 0.0082 \sin \frac{5\pi x}{l} - 0.0064 \sin \frac{6\pi x}{l} - 0.0024 \sin \frac{7\pi x}{l} - \cdots\right) \quad (g)$$

The number of terms which are shown in series (*g*) is sufficient to get values of the deflections with an error smaller than one per cent.

The obtained deflection curve is also the influence line for the deflection at the quarter point *C* in Fig. 7*b*. Using it as explained in the preceding article, the portion of the truss which must be covered with live load to produce maximum bending moment at *C* will be determined.

The equation of the deflection curve produced by live load uniformly distributed along a portion of the truss, Fig. 8, can be readily obtained from equation (32) it is only necessary

to substitute therein pdc, instead of P, and integrate from $c = a$ to $c = b$. In this manner we obtain

$$\eta = -\frac{32H_p f l^2}{\pi^3 EI} \sum_{m=1,3,5,\ldots}^{\infty} \frac{\sin\frac{m\pi x}{l}}{m^3(m^2\pi^2 + k^2l^2)} + \frac{2pl^4}{\pi^3 EI} \sum_{m=1,2,3,\ldots}^{\infty} \frac{\cos\frac{m\pi(l-b)}{l} - \cos\frac{m\pi(l-a)}{l}}{m^3(m^2\pi^2 + k^2l^2)} \sin\frac{m\pi x}{l}.$$

Observing that

$$\frac{8fH_w}{l^2} = w,$$

and introducing notations

$$\frac{H_p}{H_w} = \beta, \quad \frac{l-b}{l} = \alpha_1, \quad \frac{l-a}{l} = \alpha_2, \tag{33}$$

we represent the deflection curve by the series

$$\eta = \sum_{m=1}^{\infty} a_m \sin\frac{m\pi x}{l} \tag{34}$$

in which

$$a_m = \frac{2l^4}{\pi^3 EI} \cdot \frac{-\beta w(1-\cos m\pi) + p(\cos m\pi\alpha_1 - \cos m\pi\alpha_2)}{m^3(m^2\pi^2 + k^2l^2)}. \tag{35}$$

The calculation of these coefficients requires the values of β and of k which depend, as we see from notations (26) and (33), on the horizontal tension H_p produced by live load p. To get the equation for calculating H_p, we substitute the series (34) into equation (16) which gives

$$\frac{H_p L}{A_c E_c} = \frac{w}{H_w} \cdot \frac{2l}{\pi}\left(a_1 + \frac{a_3}{3} + \frac{a_5}{5} + \cdots\right) + \frac{\pi^2}{4l}(a_1^2 + 2^2a_2^2 + 3^2a_3^2 + \cdots) \tag{36}$$

This equation can be solved by successive approximations. As a first approximation we can take for H_p the value corresponding to an unstiffened and inextensible cable, as was

done in the preceding article. With this approximate value of H_p we calculate β and k and find the coefficients $a_1, a_2, \cdots$ from equation (35). Substituting these values into the right side of equation (36), we will find that the equation is not satisfied. We then repeat the calculation with a somewhat smaller value for H_p. From two such calculations a sufficiently accurate value of H_p can be obtained by interpolation. Calculations of this kind were made for the Ambassador Bridge in Detroit * and comparison of the obtained values of H_p with those found from the simplified equation (17) showed that the effect of the second term on the right side of equation (36) is small. It was of the order of one per cent. for a live load p = 2,000 lbs. per foot covering half of the span. This term takes care of non-uniformity in the distribution of vertical pull transmitted to the cable and it must become more important in the cases of more concentrated actions of live load. When the tension H_p, from equation (36), and the deflections η, from series (34) have been found, we calculate the maximum bending moment at C by using equation (19).

In the case of a combined action of live load and temperature change, the method of series can also be used. In such a case it will only be necessary to put on the left side of equation (36) $H_s L/A_c E_c + \epsilon t L_1$, instead of $H_p L/A_c E_c$, and use the notations $\beta = H_s/H_w$ and $k^2 = (H_w + H_s)/EI$ in formula (35).

6. THREE SPAN SUSPENSION BRIDGES WITH SIMPLY SUPPORTED STIFFENING TRUSSES.

The methods of analysis of a single span suspension bridge discussed in the two preceding articles can be readily extended to the case of several spans if each span is stiffened by a separate simply supported truss. Let us consider, for example, a symmetrical three span bridge as shown in Fig. 9. We assume that the cable can slide without friction at the tops of the towers or that the towers are very flexible. Then the horizontal component H_p of the tension produced in the cable by live load is the same for all three spans, and in its calculation we can again use equation (16). The quantity

* See the above mentioned paper by A. A. Jakkula.

L (see p. 223) in such a case is obtained by extending the integration over all three spans which gives *

$$L = \int_0^l \left(\frac{ds}{dx}\right)^3 dx + 2\int_0^{l_1} \left(\frac{ds}{dx}\right)^3 dx. \qquad (a)$$

Applying the trigonometric series in our analysis and assuming that live load is applied on the middle span we can use for the deflection of this span the previously obtained series (34), the coefficients of which are calculated from formula (35).

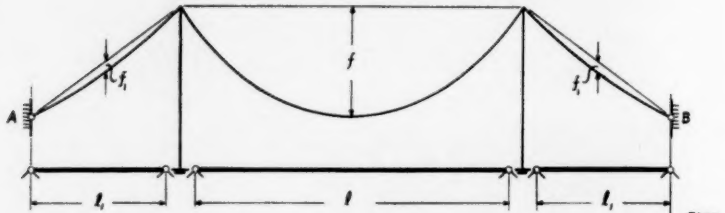

FIG. 9.

The side spans will be bent by the upward pull of the hangers, and from symmetry follows that their deflection curves will be identical. Considering the left-hand span and taking the origin of the coordinates at the left support, we can represent the deflections η_1 of this span by the following series

$$\eta_1 = c_1 \sin\frac{\pi x}{l_1} + c_2 \sin\frac{2\pi x}{l_1} + c_3 \sin\frac{3\pi x}{l_1} + \cdots \qquad (37)$$

The coefficients in this series are obtained from formula (35) by taking $p = 0$ and substituting the quantities l_1, I_1, w_1 and k_1, instead of l, I, w and k, for the side span. Then

$$c_m = -\frac{2l_1^4}{\pi^3 EI_1}\,\frac{\beta w_1(1 - \cos m\pi)}{m^3(m^2\pi^2 + k_1^2 l_1^2)}. \qquad (38)$$

Substituting series (34) and (37) and the quantity L, from equation (a), into equation (16), we obtain the following

* We assume the spans of the trusses and the corresponding spans of the cable equal.

equation for calculating H_p

$$\frac{H_p L}{A_c E_c} = \frac{2}{\pi H_w}\left(lw \sum_{1,3,5,\ldots} \frac{a_m}{m} + 2l_1 w_1 \sum_{1,3,5,\ldots} \frac{c_m}{m} \right) + \frac{\pi^2}{4} \cdot \sum_{1,2,3,\ldots} \left(\frac{a_m{}^2}{l} + \frac{2c_m{}^2}{l_1} \right) m^2. \quad (39)$$

This equation can be solved by the trial and error method used in the previous article for solution of equation (36). When H_p has been found, the deflections of the trusses are calculated by using series (34) and (37) and the moments are found from equation (19).

If, instead of trigonometric series, the expressions (27) to (29) are used for the deflection curves of the stiffening trusses, we apply the simplified equation (17) in calculating H_p. Observing that in this case the quantity L is given by equation (*a*) and extending the integration on the right-hand side of equation (17) over all three spans, we obtain for calculation H_p the following equation

$$H_p \left\{ \frac{L(H_w + H_p)}{A_c E_c l} + \frac{1}{12}\left(\frac{8f}{l}\right)^2 \left(1 - \frac{12}{k^2 l^2} + \frac{24 \tanh \frac{kl}{2}}{k^3 l^3} \right) + \frac{2}{12}\left(\frac{8f_1}{l_1}\right)^2 \frac{l_1}{l} \left(1 - \frac{12}{k_1{}^2 l_1{}^2} + \frac{24 \tanh \frac{k_1 l_1}{2}}{k_1{}^3 l_1{}^3} \right) \right\}$$
$$= P \frac{8f}{l} \left\{ \frac{1}{2}\frac{c}{l}\left(1 - \frac{c}{l} \right) - \frac{1}{k^2 l^2 \sinh kl} \times [\sinh kl - \sinh kc - \sinh k(l - c)] \right\}. \quad (40)$$

Comparing this equation with equation (30) for a single span bridge, we see that the difference is represented by the last term on the left-hand side of equation (40). Due to the presence of this term the magnitude of H_p becomes smaller than in the case of a single span bridge having the same dimensions as the middle span in Fig. 9.

Substituting into equation (40) pdc, instead of P, and integrating with respect to c, an equation for H_p is obtained

for the case in which live load is distributed along a portion of the middle span of the bridge.

7. THREE SPAN SUSPENSION BRIDGE WITH CONTINUOUS STIFFENING TRUSS.*

Let us consider a symmetrical three span bridge with a uniform continuous stiffening truss as shown in Fig. 10*a*.

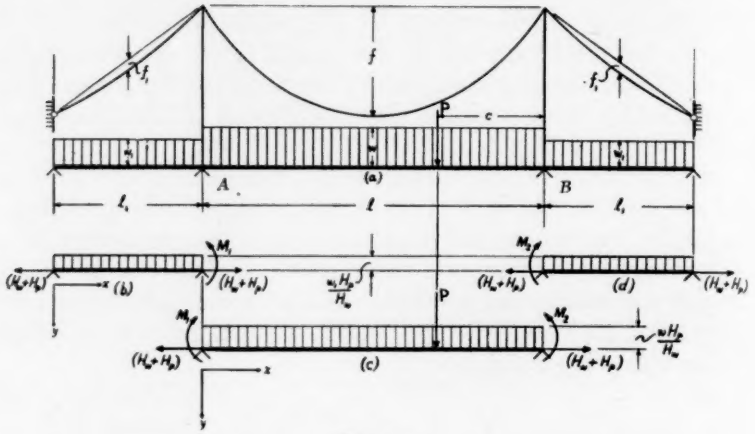

FIG. 10.

For the deflection curve of each span equation (21) will be used, in which $\mathfrak{M}_p$ will now denote the bending moment in a simply supported beam due to live load and the moments M_1 and M_2 at the supports A and B. We begin with the case in which, in addition to dead load w and w_1, one concentrated force P is applied at a distance c from support B. The corresponding free-body diagrams for the three spans are shown in Fig. 10*b*, *c*, *d*.

The magnitude of the bending moments M_1 and M_2 will now be found from the conditions that at the supports A and B the deflection curves of the two adjacent spans have a common tangent. Deflections produced by the concentrated load P and the upward pull of the hangers are given by equations (27) to (29). To obtain deflections produced by a couple applied at the end of a beam, we use equation (27), and assume that the distance c indefinitely decreases while the

* See the paper by S. Timoshenko and S. Way, Publications International Assoc. for Bridge and Structural Engineering, Vol. 2, p. 452, 1934.

moment Pc remains constant and equal to M. Then equation (27) gives

$$\eta = \frac{M}{H_w + H_p}\left(\frac{x}{l} - \frac{\sinh kx}{\sinh kl}\right). \tag{41}$$

and by differentiation, we obtain

$$\left(\frac{d\eta}{dx}\right)_{x=0} = \frac{M}{l(H_w + H_p)}\left(1 - \frac{kl}{\sinh kl}\right)$$

$$= \frac{Ml}{6EI}\cdot\frac{6}{k^2l^2}\left(1 - \frac{kl}{\sinh kl}\right), \tag{42}$$

$$\left(\frac{d\eta}{dx}\right)_{x=l} = \frac{M}{l(H_w + H_p)}\left(1 - \frac{kl}{\tanh kl}\right)$$

$$= -\frac{Ml}{3EI}\cdot\frac{3}{k^2l^2}\left(\frac{kl}{\tanh kl} - 1\right). \tag{43}$$

The slopes produced by the concentrated force P are obtained by differentiation of equations (27) and (28) which gives

$$\left(\frac{d\eta}{dx}\right)_{x=0} = \frac{P}{H_w + H_p}\left(\frac{c}{l} - \frac{\sinh kc}{\sinh kl}\right), \tag{44}$$

$$\left(\frac{d\eta}{dx}\right)_{x=l} = -\frac{P}{H_w + H_p}\left(\frac{l-c}{l} - \frac{\sinh k(l-c)}{\sinh kl}\right). \tag{45}$$

Finally the slopes produced by the upward pull are obtained by differentiation of equation (29) which gives

$$\left(\frac{d\eta}{dx}\right)_{x=0} = -\left(\frac{d\eta}{dx}\right)_{x=l} = -\frac{H_p}{H_w}\frac{wl^3}{24EI}$$

$$\cdot\frac{24}{k^3l^3}\left(\frac{kl}{2} - \tanh\frac{kl}{2}\right). \tag{46}$$

To simplify our writing, we introduce the following notations:

$$\left.\begin{aligned}\frac{6}{k^2l^2}\left(1 - \frac{kl}{\sinh kl}\right) &= \varphi,\\ \frac{3}{k^2l^2}\left(\frac{kl}{\tanh kl} - 1\right) &= \psi,\\ \frac{24}{k^3l^3}\left(\frac{kl}{2} - \tanh\frac{kl}{2}\right) &= \theta.\end{aligned}\right\} \tag{47}$$

With these notations the slopes at the ends of the middle span produced by all forces shown in Fig. 10*c* are

$$\left(\frac{d\eta}{dx}\right)_{x=0} = \frac{M_2 l}{6EI}\cdot\varphi + \frac{M_1 l}{3EI}\cdot\psi - \frac{H_p}{H_w}\frac{wl^3}{24EI}\theta + \frac{P}{H_w + H_p}\left(\frac{c}{l} - \frac{\sinh kc}{\sinh kl}\right),$$

$$\left(\frac{d\eta}{dx}\right)_{x=l} = -\frac{M_1 l}{6EI}\varphi - \frac{M_2 l}{3EI}\psi + \frac{H_p}{H_w}\frac{wl^3}{24EI}\theta - \frac{P}{H_w + H_p}\left[\frac{l-c}{l} - \frac{\sinh k(l-c)}{\sinh kl}\right].$$

Similarly the slopes at the ends of the two side spans can be obtained. It is only necessary to substitute l_1 and w_1 for l and w, and to denote by φ_1, ψ_1, and θ_1 the corresponding values of the functions (47). The conditions of continuity at the supports A and B give us then the following two equations

$$2M_1(l\psi + l_1\psi_1) + M_2 l\varphi = \frac{H_p}{4H_w}(l_1^3 w_1\theta_1 + l^3 w\theta) + \frac{6P}{k^2}\left(\frac{\sinh kc}{\sinh kl} - \frac{c}{l}\right), \quad (48)$$

$$M_1 l\varphi + 2M_2(l\psi + l_1\psi_1) = \frac{H_p}{4H_w}(l_1^3 w_1\theta_1 + l^3 w\theta) + \frac{6P}{k^2}\left[\frac{\sinh k(l-c)}{\sinh kl} - \frac{l-c}{l}\right]. \quad (49)$$

From these equations the moments M_1 and M_2 at the supports can be calculated if the additional horizontal tension H_p produced by the live load P is known.

For calculation of H_p we use the simplified equation (17). Then, extending the integration over all three spans and using the notation

$$L = \int_0^l \left(\frac{ds}{dx}\right)^3 dx + 2\int_0^{l_1}\left(\frac{ds}{dx}\right)^3 dx,$$

we obtain

$$\frac{H_p L}{A_c E_c} = \frac{w}{H_w}\int_0^l \eta dx + \frac{w_1}{H_w}\int_0^{l_1}\eta_1 dx + \frac{w_1}{H_w}\int_0^{l_1}\eta_2 dx. \quad (50)$$

In this equation η, η_1 and η_2 are the deflections of the three spans produced by the loads indicated in Figures 10*c*, *b*, *d*, respectively. Using equations (27), (28), (29) and (41), we obtain for these deflections the following expressions:
For $x < (l - c)$,

$$\eta = -\frac{P}{(H_w + H_p)} \cdot \frac{\sinh kc}{k \sinh kl} \sinh kx + \frac{Pcx}{l(H_w + H_p)} - \frac{H_p}{H_w} \frac{wl^2}{(H_w + H_p)} \left[\frac{1}{k^2 l^2 \cosh \frac{kl}{2}} \times \cosh \left(\frac{kl}{2} - kx \right) - \frac{1}{k^2 l^2} + \frac{x(l - x)}{2l^2} \right] + \frac{M_1}{(H_w + H_p)} \left[\frac{l - x}{l} - \frac{\sinh k(l - x)}{\sinh kl} \right] + \frac{M_2}{(H_w + H_p)} \left(\frac{x}{l} - \frac{\sinh kx}{\sinh kl} \right). \quad (51)$$

For $x > l - c$,

$$\eta = -\frac{P}{(H_w + H_p)} \frac{\sinh k(l - c)}{k \sinh kl} \sinh k(l - x) + \frac{P(l - c)(l - x)}{l(H_w + H_p)} - \frac{H_p}{H_w} \frac{wl^2}{(H_w + H_p)} \left[\frac{1}{k^2 l^2 \cosh \frac{kl}{2}} \times \cosh \left(\frac{kl}{2} - kx \right) - \frac{1}{k^2 l^2} + \frac{x(l - x)}{2l^2} \right] + \frac{M_1}{(H_w + H_p)} \left[\frac{l - x}{l} - \frac{\sinh k(l - x)}{\sinh kl} \right] + \frac{M_2}{(H_w + H_p)} \left(\frac{x}{l} - \frac{\sinh kx}{\sinh kl} \right). \quad (52)$$

$$\eta_1 = \frac{M_1}{(H_w + H_p)}\left(\frac{x}{l_1} - \frac{\sinh kx}{\sinh kl_1}\right) - \frac{H_p}{H_w}\cdot\frac{w_1 l_1^2}{(H_w + H_p)}\left[\frac{1}{k^2 l_1^2 \cosh\frac{kl_1}{2}}\cosh\left(\frac{kl_1}{2} - kx\right) - \frac{1}{k^2 l_1^2} + \frac{x(l_1 - x)}{2l_1^2}\right]. \quad (53)$$

$$\eta_2 = \frac{M_2}{(H_w + H_p)}\left[\frac{l_1 - x}{l_1} - \frac{\sinh k(l_1 - x)}{\sinh kl_1}\right] - \frac{H_p}{H_w}\frac{w_1 l_1^2}{(H_w + H_p)}\left[\frac{1}{k^2 l_1^2 \cosh\frac{kl_1}{2}}\cosh\left(\frac{kl_1}{2} - kx\right) - \frac{1}{k^2 l_1^2} + \frac{x(l_1 - x)}{2l_1^2}\right]. \quad (54)$$

Substituting these expressions into equation (50), we obtain

$$H_p\left[\frac{(H_w+H_p)L}{A_c E_c} + \left(\frac{w}{H_w}\right)^2\left(\frac{2}{k^3}\tanh\frac{kl}{2} - \frac{l}{k^2} + \frac{l^3}{12}\right) + 2\left(\frac{w_1}{H_w}\right)^2\left(\frac{2}{k^3}\tanh\frac{kl_1}{2} - \frac{l_1}{k^2} + \frac{l_1^3}{12}\right)\right] = \frac{w}{H_w}\left\{\frac{Pc(l-c)}{2} - \frac{P}{k^2\sinh kl}[\sinh kl - \sinh kc - \sinh k(l-c)] + (M_1+M_2)\mathrm{X}\right\} \quad (55)$$

where

$$\mathrm{X} = \frac{k^2}{24}\left(\theta l^3 + \frac{w_1}{w}\theta_1 l_1^3\right). \quad (56)$$

Equations (48), (49) and (55) define the three statically indetermined quantities M_1, M_2 and H_p.

In calculating these quantities we determine first the value of $M_1 + M_2$ by adding together equations (48) and (49).

Substituting this value into equation (55) we obtain

$$H_p\left[\frac{(H_w+H_p)L}{A_cE_cl}+\frac{1}{12}\left(\frac{8f}{l}\right)^2\left(1-\frac{12}{k^2l^2}+\frac{24\tanh\frac{kl}{2}}{k^3l^3}\right)\right.$$
$$+\frac{1}{6}\left(\frac{8f_1}{l_1}\right)^2\frac{l_1}{l}\left(1-\frac{12}{k^2l_1^2}+\frac{24\tanh\frac{kl_1}{2}}{k^3l_1^3}\right)$$
$$\left.-\frac{1}{2}\left(\frac{8f}{l}\right)^2\left(\theta+\frac{w_1}{w}\frac{l_1^3}{l^3}\theta_1\right)\frac{X}{2(l\psi+l_1\psi_1)+l\varphi}\right]$$
$$=P\frac{8f}{l}\left\{\frac{1}{2}\frac{c}{l}\left(1-\frac{c}{l}\right)-\frac{\sinh kl-\sinh kc-\sinh k(l-c)}{k^2l^2\sinh kl}\right.$$
$$\left.\times\left[1+\frac{6X}{2(l\psi+l_1\psi_1)+l\varphi}\right]\right\}. \quad (57)$$

From this equation H_p can be calculated for any position of the live load P. Substituting H_p into equations (48) and (49), the moments at the supports will be found.

To apply equation (57) for the construction of influence lines, we neglect H_p in comparison with H_w and assume that $k^2 \approx H_w/EI$. With this value of k^2 the value of H_p can be readily calculated from equation (57) for any position of the load and the influence line for H_p can be constructed. Take as an example, the case in which $l_1 = \frac{1}{2}l$, $w_1 = w$, $kl = 10$, $f/l = 0.1$, $(H_wL/A_cE_cl) = 0.0043$. Substituting these numerical values into equation (57), we obtain

$$0.0753H_p = 0.8P\left\{\frac{1}{2}\frac{c}{l}\left(1-\frac{c}{l}\right)\right.$$
$$\left.-\frac{3.12}{100}\left[1-\frac{\sinh kc}{\sinh kl}-\frac{\sinh k(l-c)}{\sinh kl}\right]\right\}.$$

From this equation the influence line of H_p for the middle span is obtained as shown in Fig. 11. For comparison there is shown by dotted line in the same figure the influence line calculated from equation (40) for the stiffening truss with hinges at the supports, Fig. 9. It is seen that by using a continuous truss, we increase the rigidity of the structure somewhat and diminish the values of H_p. Having the in-

fluence line for H_p, we can construct the influence lines for M_1 and M_2 by using equations (48) and (49). The influence lines for deflections will then be obtained from equations (51) to (54) and those for bending moments, from equation (19). Having all these lines the most unfavorable position of live load can be determined.

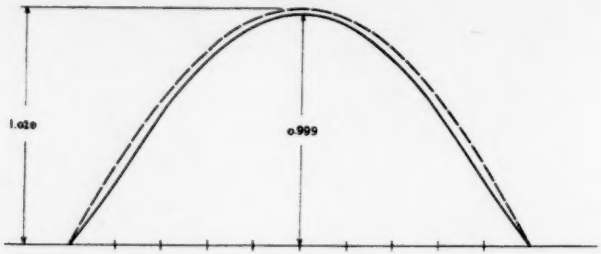

FIG. 11.

Assume now that the live load is distributed along a portion of the middle span as shown in Fig. 8. Then to obtain an equation for calculation of H_p, we use equation (57) and apply the method of superposition. Substituting pdc, instead of P, in equation (57) and integrating the right-hand side with respect to c from $c = a$ to $c = b$, we obtain

$$H_p\left[\frac{(H_w+H_p)L}{A_cE_cl}+\frac{1}{12}\left(\frac{8f}{l}\right)^2\left(1-\frac{12}{k^2l^2}+\frac{24\tanh\frac{kl}{2}}{k^3l^3}\right)\right.$$
$$+\frac{1}{6}\left(\frac{8f_1}{l_1}\right)^2\frac{l_1}{l}\left(1-\frac{12}{k^2l_1^2}+\frac{24\tanh\frac{kl_1}{2}}{k^3l_1^3}\right)$$
$$\left.-\frac{1}{2}\left(\frac{8f}{l}\right)^2\left(\theta+\frac{w_1}{w}\frac{l_1^3}{l^3}\theta_1\right)\frac{X}{2(l\psi+l_1\psi_1)+l\varphi}\right]$$
$$=8pf\left\{\frac{3l(b^2-a^2)-2(b^3-a^3)}{12l^3}-\frac{1}{k^2l^2}\left[\frac{b-a}{l}\right.\right.$$
$$\left.-\frac{\cosh kl-\cosh ka+\cosh k(l-a)-\cosh k(l-b)}{kl\sinh kl}\right]$$
$$\left.\times\left[1+\frac{6X}{2(l\psi+l_1\psi_1)+l\varphi}\right]\right\}. \quad (58)$$

This equation, instead of equation (57), must be used for calculation H_p if live load is distributed along a portion of the middle span. In a similar manner equations can be derived if the load is on one of the lateral spans.

If in addition to live load action we have to take into account a temperature change, the equation for calculating the change H_s in the horizontal tension in the cable is obtained by substituting (see p. 232) $(H_s L/A_c E_c) + \epsilon t L_1$ instead of $H_p L/A_c E_c$ into equation (50). This gives

$$H_s\left[\frac{(H_w+H_s)L}{A_cE_cl}+\frac{\epsilon tL_1}{l}+\frac{1}{12}\left(\frac{8f}{l}\right)^2\left(1-\frac{12}{k^2l^2}+\frac{24\tanh\frac{kl}{2}}{k^3l^3}\right)\right.$$
$$+\frac{1}{6}\left(\frac{8f_1}{l_1}\right)^2\frac{l_1}{l}\left(1-\frac{12}{k^2l_1^2}+\frac{24\tanh\frac{kl_1}{2}}{k^3l_1^3}\right)$$
$$\left.-\frac{1}{2}\left(\frac{8f}{l}\right)^2\left(\theta+\frac{w_1}{w}\frac{l_1^3}{l^3}\theta_1\right)\frac{X}{2(l\psi+l_1\psi_1)+l\varphi}\right]$$
$$=-\frac{H_w\epsilon tL_1}{l}+8pf\left\{\frac{3l(b^2-a^2)-2(b^3-a^3)}{12l^3}-\frac{1}{k^2l^2}\left[\frac{b-a}{l}\right.\right.$$
$$\left.\left.-\frac{\cosh kl-\cosh ka+\cosh k(l-a)-\cosh k(l-b)}{kl\sinh kl}\right]\right.$$
$$\left.\times\left[1+\frac{6X}{2(l\psi+l_1\psi_1)+l\varphi}\right]\right\}. \quad (59)$$

From this equation H_s can be calculated by trial and error as has been done in previous cases. Take, as a numerical example, the case in which $l = 800$ ft., $l_1 = 400$ ft., $f/l = 0.105$, $f_1/l_1 = 0.0525$, $H_w = 3.667 \cdot 10^6$ lbs., $EI = 56.84 \cdot 10^9$ lbs. ft.^{2}, $pl = 0.28361\ H_w$, $\epsilon = 65.10^{-7}$, $t = 60°$ F., $A_c = 87.8$ in.^{2}, $E_c = 29.10^6$ lbs. per sq. in., $L/l = 2.5937$, $L_1/l = 2.4975$. For $b = l$ and for various values of the ratio a/l equation (59) gives for H_s the values written in the second line of Table II below. The negative values of H_s for small amounts of live load is due to the fact that the temperature rise of 60°, which we have assumed, expands the cable, allowing part of the dead load to be taken by the stiffening truss.

TABLE II.

$\frac{a}{l}$ =	0	0.1	0.2	0.3	0.4	0.5
$\frac{H_s}{H_w}$ =	0.2430	0.2386	0.2230	0.1930	0.1535	0.1082
$\frac{M_1 l}{EI}$ =	−0.016	−0.0188	−0.0290	−0.0500	−0.0742	−0.096
$\frac{M_2 l}{EI}$ =	−0.016	0.003	0.032	0.050	0.052	0.041

$\frac{a}{l}$ =	0.6	0.7	0.8	0.9	1
$\frac{H_s}{H_w}$ =	0.0625	0.0222	−0.0085	−0.0258	−0.0305
$\frac{M_1 l}{EI}$ =	−0.110	−0.1085	−0.0908	−0.0628	−0.0445
$\frac{M_2 l}{EI}$ =	0.018	−0.007	−0.028	−0.041	−0.0445

To obtain values of the moments M_1 and M_2 at the supports, we use equations (48) and (49). Substituting pdc, instead of P, and integrating from $c = a$ to $c = b$, we obtain

$$2M_1(l\psi + l_1\psi_1) + M_2 l\varphi = \frac{H_p}{4H_w}(l_1^3 w_1\theta_1 + l^3 w\theta) + \frac{6pl}{k^2}\left(\frac{\cosh kb - \cosh ka}{kl \sinh kl} - \frac{b^2 - a^2}{2l^2}\right),$$

$$M_1 l\varphi + 2M_2(l\psi + l_1\psi_1) = \frac{H_p}{4H_w}(l_1^3 w_1\theta_1 + l^3 w\theta) + \frac{6pl}{k^2} \times \left[\frac{\cosh k(l-a) - \cosh k(l-b)}{kl \sinh kl} - \frac{2l(b-a) - (b^2 - a^2)}{2l^2}\right]. \quad (60)$$

From these equations M_1 and M_2 can be calculated provided H_p is found from equation (58). Similar equations are obtained also when a combined action of live load and temperature change are considered. The values of the moments calculated from these equations for our numerical example are

given in the third and the fourth lines of Table II. The variation of H_s/H_w and of M_1l/EI and M_2l/EI with the length $l - a$ of the loaded portion of the middle span is shown in Fig. 12. We see that the moment at the left tower is greatest when the live load extends over 35 per cent. of the main span.

To show the effect of continuity of the stiffening truss at the support, there is given in Fig. 12 also the curve for H_s calculated on the assumption that there are hinges at the supports A and B. In making this later calculation, we have

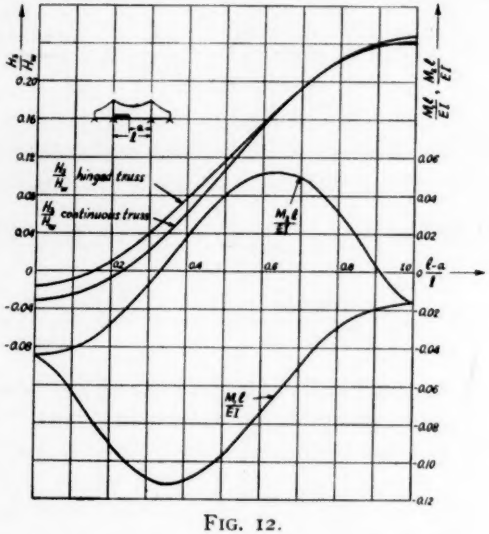

FIG. 12.

only to omit in equation (58) the terms containing the function X. It is seen that in the case of hinged spans the H_s curve is somewhat above the corresponding curve for continuous truss.

8. STIFFENING TRUSS OF VARIABLE CROSS SECTION.

The method of trigonometric series previously applied (see art. 5) to a stiffening truss of uniform cross section can be extended also to cases in which the stiffening truss has a variable cross section.* We start with the differential equa-

* This extension of the application of trigonometric series was shown by E. Steuerman in his discussion of the writer's paper, see Trans. Am. Soc. C. E., Vol. 94, p. 377, 1930.

tion for the deflection curve of the stiffening truss (eq. (e), p. 328)

$$EI\frac{d^2\eta}{dx^2} - (H_w + H_p)\eta = \sum b_m \sin\frac{m\pi x}{l}, \qquad (a)$$

in which

$$b_m = \frac{2}{l}\int_0^l (H_p y - \mathfrak{M}_p)dx.$$

For the case of one concentrated load P, Fig. 6, we have (see p. 328)

$$b_m = \frac{16H_p f}{m^3\pi^3}(1 - \cos m\pi) - \frac{2Pl}{m^2\pi^2}\sin\frac{m\pi(l-c)}{l}. \qquad (b)$$

For the case of distributed load, as in Fig. 8, we obtain b_m by substituting pdc, instead of P, into equation (b) and integrating from $c = a$ to $c = b$, which gives

$$b_m = \frac{2l^2}{m^3\pi^3}\left\{\frac{8fH_p}{l^2}(1 - \cos m\pi) - p\left[\cos\frac{m\pi(l-b)}{l} - \cos\frac{m\pi(l-a)}{l}\right]\right\}. \qquad (c)$$

Applying now equation (a) to the case of a truss of variable cross section, we assume that the flexural rigidity of the truss is defined by the equation:

$$EI = EI_0\varphi(x), \qquad (d)$$

in which $\varphi(x)$ is a known function of x, and take the solution of equation (a) in form of the series

$$\eta = \sum_{m=1}^{\infty} a_m \sin\frac{m\pi x}{l}. \qquad (e)$$

Substituting expressions (d) and (e) into equation (a), we obtain

$$-\frac{\pi^2}{l^2}EI_0\varphi(x)\sum_{m=1}^{\infty} m^2 a_m \sin\frac{m\pi x}{l} - (H_w + H_p)\sum_{m=1}^{\infty} a_m \sin\frac{m\pi x}{l} = \sum_{m=1}^{\infty} b_m \sin\frac{m\pi x}{l}. \qquad (f)$$

To calculate the coefficients $a_1, a_2, a_3, \cdots$ of the series (*e*), we multiply equation (*f*) by $\sin(i\pi x/l)$, where $i = 1, 2, 3, \cdots$, and integrate from $x = 0$ to $x = l$. In this manner we obtain

$$-\frac{2\pi^2}{l^3} EI_0 \sum_{m=1}^{\infty} m^2 a_m \int_0^l \varphi(x) \sin\frac{m\pi x}{l} \sin\frac{i\pi x}{l}\, dx - a_i(H_w + H_p) = b_i. \quad (g)$$

After calculation of the integral on the left side, we obtain a linear equation containing the unknown coefficients $a_1, a_2, a_3, \cdots$. In practical calculations we take only the first few terms of the series (*e*). Let n denote the number of these terms. Then taking $i = 1, 2, \cdots n$. We obtain n linear equations (*g*) from which n coefficients $a_1, a_2, \cdots a_n$ of the series (*e*) can be calculated for any assumed value of H_p. To determine H_p we use the previous equation (36):

$$\frac{H_p L}{A_c E_c} = \frac{16f}{\pi l}\left(a_1 + \frac{a_3}{3} + \cdots + \frac{a_n}{n}\right) + \frac{\pi^2}{4l}(a_1^2 + 2^2 a_2^2 + \cdots + n^2 a_n^2). \quad (h)$$

This equation together with n equations (*g*) are sufficient for the solution of the problem. In each particular case, we start with a calculation of the coefficients b_m for the assumed live load distribution by using equation (*b*) or equation (*c*). Then we calculate the integral on the left side of equations (*g*) for the assumed $\varphi(x)$ and obtain n linear equations for the coefficients $a_1, a_2, \cdots a_n$. Taking now, as a trial, a certain value for H_p, we calculate these coefficients and substitute them into the right-hand side of equation (*h*). Since the value of H_p was taken arbitrarily, the equation will not be satisfied and a second trial value of H_p must be taken. After two such trials the correct value of H_p can be obtained with sufficient accuracy by interpolation. Such calculations show that considerable variations of flexural rigidity EI along the span of the truss have only a small effect on the magnitude of H_p, and that a very good approximation for H_p is obtained by replacing a variable flexural rigidity by its constant average value.

To illustrate the calculations required in the case of a truss of variable cross section, let us assume that

$$EI = EI_0 \sin\left(\frac{s\pi x}{l} + \alpha\right). \tag{i}$$

To have a truss symmetrical with respect to the middle we take

$$s\pi + \alpha = \pi - \alpha.$$

Then

$$s = 1 - \frac{2\alpha}{\pi}, \tag{j}$$

and equation (*i*) gives

$$(EI)_{x=0,\,x=l} = EI_0 \sin\alpha, \quad (EI)_{x=l/2} = EI_0. \tag{k}$$

Taking for example $\alpha = \pi/6$, we obtain $s = 2/3$ and the flexural rigidity at the ends of the truss is only half of that at the middle. The integral in equation (*g*), for

$$\varphi(x) = \sin\left[(s\pi x/l) + \alpha\right],$$

is

$$\int_0^l \sin\left(\frac{s\pi x}{l} + \alpha\right) \sin\frac{m\pi x}{l} \sin\frac{i\pi x}{l}\, dx = \frac{2[(-1)^{m+i+1} - 1]slmi\cos\alpha}{\pi[(m-i)^2 - s^2][(m+i)^2 - s^2]}, \tag{l}$$

and equation (*g*) becomes

$$-\frac{4\pi s\cos\alpha}{l^2} EI_0 \sum_{m=1}^{m=n} a_m \frac{im^3[(-1)^{m+i+1} - 1]}{[(m-i)^2 - s^2][(m+i)^2 - s^2]} - a_i(H_w + H_p) = b_i$$

Introducing the notations

$$\frac{4\pi s\cos\alpha EI_0}{l^2(H_w + H_p)} = \mu, \tag{m}$$

$$\frac{im^3[(-1)^{m+i+1} - 1]}{[(m-i)^2 - s^2][(m+i)^2 - s^2]} = N_{mi}, \tag{n}$$

$$\frac{b_i}{H_w + H_p} = c_i, \tag{o}$$

we represent equations (*g*) for calculation of the coefficients $a_1, a_2, \cdots a_n$ in the following form

$$a_i + \mu \sum_{m=1}^{m=n} a_m N_{mi} + c_i = 0, \quad i = 1, 2, \cdots n. \qquad (p)$$

Assuming, for example, that $\alpha = \pi/6$, $s = 2/3$, and taking only four terms of the series (*e*), we obtain for calculation of the four coefficients the following four equations:

$$\begin{aligned}
&a_1 + \mu \left(\frac{81}{64} a_1 - \frac{27 \cdot 81}{16 \cdot 140} a_3 \right) + c_1 = 0 , \\
&a_2 + \mu \left(\frac{162}{35} a_2 - \frac{81}{40} a_4 \right) + c_2 = 0 , \\
&a_3 + \mu \left(- \frac{243}{16 \cdot 140} a_1 + \frac{81^2}{640} a_3 \right) + c_3 = 0 , \\
&a_4 + \mu \left(- \frac{81}{160} a_2 + \frac{31 \cdot 81}{143} a_4 \right) + c_4 = 0 .
\end{aligned} \qquad (q)$$

It is seen that this system of equations is split into two groups, one containing the coefficients a_1, a_3 of odd order, and the other containing the coefficients a_2, a_4 of even order. The solution of these equations for any numerical values of μ, c_1, c_2, c_3, c_4 can be readily accomplished. For a truss of given dimensions and for an assumed value of H_p, we calculate the value of μ from equation (*m*). The quantities $c_1, \cdots c_4$, for a given load distribution, are calculated from equation (*o*). Then the coefficients $a_1 \cdots a_4$ will be found from equations (*q*). Substituting these coefficients into equation (*h*), we check how accurately the assumed value of H_p satisfies this equation. With two trial calculations we find the correct value of H_p and the corresponding values of the coefficients. Equation (*e*) then gives the deflection curve. The bending moments will be found from equation (19). Calculations made for a single span bridge of the same dimensions as the middle span of the Manhattan Bridge and for live load distributed from $x = 0$ to $x = l/4$ show that the horizontal tension H_p calculated for the constant rigidity EI_0 diminishes only by about one per cent. when the rigidity of the truss, given by

equation (*i*), is reduced at the ends to one half of its value at the middle.

Calculation of M_{max} for a truss of uniform cross section shows that this quantity varies along the span as shown in Fig. 13*a*. It is seen that a rational design requires a reinforcement of the cross section of the truss near the quarter points and not at the middle of the span, as was assumed in the

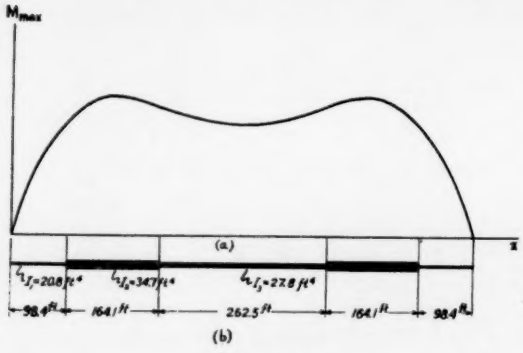

FIG. 13.

preceding example. A proper variation in flexural rigidity along the span may be represented by the equation

$$EI = \frac{EI_0}{1 - \alpha}\left(1 - \alpha \cos\frac{4\pi x}{l}\right). \qquad (r)$$

Substituting

$$\varphi(x) = \frac{1}{1 - \alpha}\left(1 - \alpha \cos\frac{4\pi x}{l}\right)$$

into equation (*g*) and proceeding as in the previous example, we obtain the deflection and the moments for a truss, the flexural rigidity of which varies according to equation (*r*).

Practically the rigidity of a truss is not a continuous function of x but changes abruptly as shown in Fig. 13*b*. Calculations made for this case * shows that while the moment of

* Such calculations, made by using a certain generalization of the series method, are given in the book by Hans H. Bleich, "Die Berechnung verankerter Hängebrücken," Julius Springer 1935, p. 63. This book contains several numerical examples completely worked out. The use of finite differences equations in handling trusses of variable cross section is shown in the paper by F. Stüssi, Publications, International Assoc. for Bridge and Structural Engineering, Vol. 4, 1936, p. 531.

inertia of the cross section differs by ± 20 per cent. of its average value, the values of M_{max} for the middle and for the quarter points differ from the corresponding values, calculated for the truss of constant average cross section, only by 2.5 per cent. and 3.5 per cent., respectively. We see that a considerable variation in the flexural rigidity along the span of the truss produces only a secondary effect on the bending moments. Hence the usual calculations based on the assumption of a truss of a constant average cross section give satisfactory results.

Refrigerated Container Designed for Food Now Speeds Blood for Red Cross.—A refrigerated container, originally developed for transporting small quantities of perishable foods that require temperature protection in transit, is now being used to carry blood from Red Cross collecting centers to laboratories where it is processed for shipment to America's armed forces overseas. Designed by Major Elihu Church, built by refrigeration experts of the General Electric Company and transported by the Railway Express Agency, the Church containers service the nation's 17 blood centers where 50,000 contributions a week are being made by blood donors. To handle the increasing donations of blood, the War Production Board has granted priorities for 200 more containers, which are now being built by General Electric. The Church Containers look like large trunks. Made of galvanized steel and mounted on casters so they may be moved easily, they have an insulation thickness of four inches and a capacity of ten cubic feet. A bunker, which may be loaded either with 100 lb. of dry ice or with 90 lb. of water ice, provides low temperatures required in refrigeration. The shipment must reach the laboratory within 24 hours and be maintained in transit at a uniform temperature close to 40° F., or the blood will deteriorate and become useless. After the blood is taken from a person's arm it is placed in pint bottles and kept in a refrigerator, the temperature of which ranges from 35° to 40° F. Meanwhile, at the blood center Church Containers are being pre-cooled during the day by blocks of dry ice and an inner bunker of water ice to a temperature of 20° below zero. At a set time in the evening, depending on train schedules to the laboratory to which the blood is to be delivered, an express truck arrives at the collection center. A container has compartments for 80 bottles, each of which is first placed in an unbleached muslin bag as soon as the collection is taken. The bottles are stacked in the containers just in time for the truck to pick them up and speed them to the railroad station for loading on to a fast train. At the end of the trip another truck delivers the containers to a laboratory. There the liquid red blood is transformed, by operations of centrifugal spinning, freezing and dehydrating, into a crystalline substance which preserves itself indefinitely, without the necessity of refrigeration.

R. H. O.

THE QUANTITATIVE DETERMINATION OF HYPO IN PHOTOGRAPHIC PRINTS WITH SILVER NITRATE.

BY

J. I. CRABTREE, G. T. EATON, AND L. E. MUEHLER*

Communication No. 911 from the Kodak Research Laboratories.

Summary. A silver nitrate test is described for the quantitative determination of residual hypo in photographic prints. The hypo is converted *in situ* to silver sulfide, the transmission density of the sulfide determined, and the hypo content obtained by reference to a standard curve.

The method used to establish the standard curve is outlined, the data being verified by quantitative analyses.

A simplified procedure is suggested involving the application of a drop of silver nitrate to the back of the print and then matching the spot visually with a set of standards.

The degree of washing of photographic prints has been determined in the past, with few exceptions (1, 2) by measurement of the hypo (sodium thiosulfate) contained in the wash water. The reagents most commonly used were iodine-starch (3), iodine-azide starch (4), potassium permanganate (5), and silver nitrate† which could be adjusted in concentration to have definite sensitivities.

However, the estimation of hypo in the wash water does not indicate the hypo content of the print. In fact, when only traces of hypo are indicated in the wash water, the print may actually contain quantities of hypo large enough to affect seriously the permanence of the print image. It is therefore imperative that the residual hypo content of the print be determined quantitatively to indicate the thoroughness of washing.

Lumière and Seyewetz (6) in 1908 and 1913 described a spot test on prints with a silver nitrate solution. They applied a drop of the solution to the edge of the print and considered the print washed when no color appeared after 2 or 3 minutes.

* Kodak Research Laboratories, Rochester, N. Y.

† There are many references to the use of silver nitrate; the pertinent ones are given later.

Weyde (7) in 1935, Weyde (8) and Freytag (9) in 1937 described the results obtained with a silver nitrate test which appeared to be quantitative. The print or a section cut from it was tested with 1 per cent. silver nitrate for 1 to 3 minutes, then treated with 5 per cent. sodium chloride, fixed in hypo, and washed. No color could be observed when the hypo content was below 0.01 gram per square meter. No details were given, however, on the standardization of the test.

A silver nitrate test was described by the authors in 1940 (10) which gave a quantitative determination of the hypo content of prints. It is the purpose of this paper to describe the standardization of this silver nitrate test.

Tests, other than the use of silver nitrate, have been tried in this connection including (1) bathing tests with iodine-azide, iodine and permanganate, (2) spot tests with iodine-azide, iodine and permanganate, and (3) the mercuric chloride test for residual hypo in film as recommended by Crabtree and Ross (11). In order to make quantitative determinations with any of these methods of testing it was necessary to standardize the technique with some quantitative method for the determination of hypo in photographic prints. Otherwise there was no assurance that the desired degree of washing was attained.

Townsend (12) proposed in 1938 that the mercuric chloride test (11) be used to determine the residual hypo in prints. This test does not give a quantitative estimate with prints, as it does with film, because it measures only the readily diffusible hypo which may be only a fraction of the total hypo content. Data are presented in a previous paper to substantiate this statement (10).

An iodine spot test was described by Cary and Wheeler (13) for use in the quantity production of enlargements but the method may not be quantitative since some fraction of the hypo retained, especially by the paper fibers, may not react in the short time designated. Spot tests, in general, do not react with all of the hypo but only with that which readily diffuses to the surface to react with the drop. The difficulty of this type of test is to apply a definite volume of reagent over a definite area of paper.

The advantage of the silver nitrate test, whether quantitative or qualitative, is that the reagent in excess reacts completely with all of the residual hypo *in situ* to produce silver sulfide in quantities directly proportional to the hypo content. The intensity of the silver sulfide stain also increases in direct proportion to the quantity of sulfide produced so that a quantitative measure of the transmission density produced by the silver sulfide would indicate a corresponding quantity of residual hypo.

The question naturally arises as to the use of the silver nitrate test with film. It has been found that transmission densities more truly indicate the quantity of silver sulfide present but that a more sensitive densitometer than the Capstaff-Purdy type is required. In addition, the mercuric chloride test has proved entirely satisfactory for the quantitative determination of residual hypo in film. However, the silver nitrate test could be used as a qualitative spot test with film.

The procedure developed for the quantitative determination of hypo in prints is described below.

Silver Nitrate Method for the Quantitative Determination of Hypo.

The test solutions required are:

Solution A

Silver nitrate	10 grams
Sulfuric acid (conc.)	5 cc.
OR	
Acetic acid (glacial)	20 cc.
Water to make	1 liter

*Solution B**

Sodium chloride	50 grams
Water to make	1 liter

Solution C

Hypo	50 grams
Sodium sulfite	20 grams
Water to make	1 liter

A sample of the non-image area of a print, at least $\frac{1}{4} \times 1$ inch, is immersed in an excess of Solution A for 3 to 5 minutes, treated in Solution B for 3 to 5 minutes, bathed in Solution C for 3 to 5 minutes, washed and dried.

* Potassium bromide has been used by the authors for this purpose but has no advantages over sodium chloride.

The transmission density of the untreated and treated samples is determined by means of a Capstaff-Purdy densitometer or similar instrument. A piece of a Wratten blue filter No. 44 is placed over the eyepiece for these readings which are made most satisfactorily in a dimly lighted room. The difference in the two readings is the transmission density of the silver sulfide produced in the paper and is proportional to the quantity of residual hypo in the print. The equivalent hypo content is then obtained from the standard curve shown in Fig. 1.

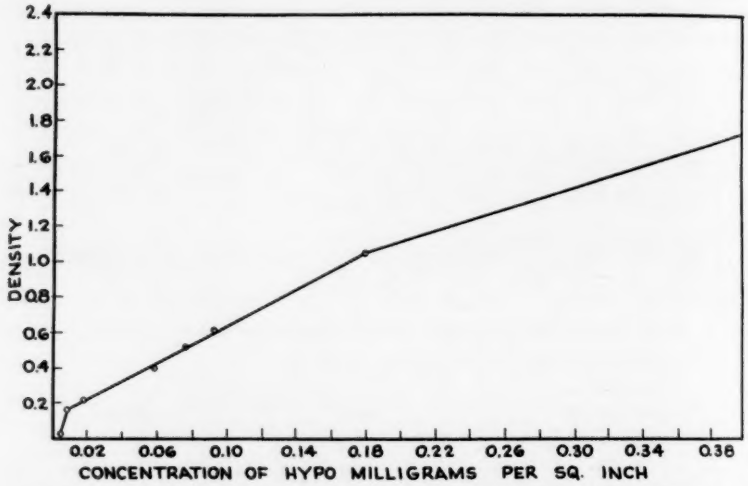

FIG. 1. Standard curve showing relation between hypo concentration and density of silver sulfide stain after treatment with silver nitrate. The "transmission densities" are the values obtained when the density of the untreated sample is subtracted from that of the treated sample.

The silver nitrate reacts *in situ* with the hypo to produce silver sulfide according to the equation

$$2AgNO_3 + Na_2S_2O_3 + HOH \rightarrow Ag_2S + 2NaNO_3 + H_2SO_4.$$

The excess silver nitrate is then converted to silver chloride which is dissolved by hypo. If an excess of silver nitrate is allowed to remain, exposure to air and light will produce a darkening of the silver sulfide stain and the resultant transmission density will not be a true measure of the hypo present in the sample.

The addition of an acid to the silver nitrate solution makes the reagent more specific for hypo because the acid prevents a reaction between silver nitrate and any sulfite that might be present (14).

Prints containing residual quantities of hypo over a wide range were treated with silver nitrate as described above and the resultant silver sulfide stains read by both transmission and reflection densitometers. The data showed that when the reflection densities became nearly constant for the higher quantities of residual hypo the transmission densities continued to increase. It was also found that smaller quantities of residual hypo could be determined by transmission than by reflection density readings. It was therefore evident that reflection densities might be misleading and consequently it was decided to determine the densities by transmission.

THE STANDARD CURVE: FIGURE 1.

Since the proposed method of analysis involved the determination of silver sulfide in terms of transmission density units, it was necessary to fulfill the following conditions in order to obtain a standardized curve which could be accurately applied to photographic prints. (1) A known quantity of hypo should be put into a definite area of photographic paper, and (2) the silver sulfide finally produced should be dispersed throughout the photographic paper in the same manner as in a processed photographic print.

It was considered that the only satisfactory basis for a quantitative method of this type was to be able to introduce a known quantity of hypo into a given area of photographic paper in a manner similar to the fixing process. If hypo was introduced in any other way it was possible that the resultant silver sulfide would not be dispersed throughout the paper base, baryta coating, etc., in the same manner as in a silver nitrate-treated photographic print and would, therefore, introduce very probable substantial differences in the resultant transmission densities. Thus, a soaking technique simulating the fixing process was used.

The photographic paper used for this purpose was coated with an emulsion without silver halide. Samples were cut

with a steel punch having an area of 0.56 square inch and each sample was carefully weighed.

Standard thiosulfate solutions were made up by dissolving the required amount of hypo in carbon dioxide-free distilled water. The very dilute solutions were made up by dilution of a 1 : 1,000 solution and each solution was used at room temperature. The solutions used were of the concentrations: 1 : 10,000; 1 : 5,000; 1 : 2,500; 1 : 1,000; 1 : 750; 1 : 500; 1 : 250, and 1 : 100.

Paper samples were soaked in each solution for 5, 15, 30 and 60 minutes and 2 and $5\frac{1}{2}$ hours. Each sample was removed from the solution, placed between pieces of unused filter paper for 10 seconds and then weighed as quickly as possible. As soon as the sample had dried at room temperature the hypo was converted to silver sulfide as described previously.

A blank determination was made by soaking samples in distilled water and then treating in the test solutions.

The transmission density due to the silver sulfide, formed by the reaction of silver nitrate and hypo, was the difference in the density readings obtained for the blank and the test samples.

The increase in weight of the sample after treatment in a hypo solution was the weight of solution absorbed by the paper. Since the increase in weight and the concentration of hypo solution were accurately known, the quantity of hypo in the sample could be calculated.

The data in Table I show the calculated quantities of hypo and the corresponding transmission densities for three of the hypo solutions used.

These data which are typical of all the hypo solutions show that for each solution the density increased while the concentration of hypo, as calculated from the solution absorbed, remained essentially constant. The obvious conclusion is that more hypo was actually present in the paper than was calculated from weight increases of the samples.

This is sufficient evidence to indicate the possible selective adsorption * of hypo or possibly some other form of retention

* These data would tend to substantiate the claims of Charriou that hypo was adsorbed by photographic papers.[3]

TABLE I.

Calculated Hypo Contents and Transmission Densities.

Concentration of Thiosulfate Solution, $Na_2S_2O_3 . 5H_2O$.	Time of Treatment.	Calculated Thiosulfate (Milligrams in Solution Absorbed).	Transmission Density (Capstaff-Purdy).
1 : 10,000	5 Min.	0.002	0.02
	15 Min.	0.003	0.06
	30 Min.	0.003	0.08
	60 Min.	0.003	0.13
	120 Min.	0.003	0.22
	330 Min.	0.003	0.45
1 : 5,000	5 Min.	0.005	0.16
	15 Min.	0.006	0.16
	30 Min.	0.006	0.21
	60 Min.	0.006	0.25
	120 Min.	0.006	0.33
	330 Min.	0.006	0.54
1 : 2,500	5 Min.	0.010	0.22
	15 Min.	0.011	0.23
	30 Min.	0.012	0.36
	60 Min.	0.011	0.45
	120 Min.	0.012	0.64
	330 Min.	0.012	0.86

by the paper. In fact, when the transmission densities are plotted against the times of treatment for each solution the resultant curves are not unlike adsorption isotherms.

Therefore, in order to obtain results by this method which would give transmission densities corresponding to a known quantity of hypo it was necessary to use soaking times short enough to avoid adsorption and long enough to be sure that the quantity of solution absorbed by the sample was constant. This time was found to be very close to 5 minutes in every case.

Table II presents the data from these tests which were used to obtain the curve in Fig. 1.

The hypo contents of photographic materials are usually reported as milligrams per square inch. Therefore, the hypo contents given in Table II were multiplied by 100/56 to establish the data on the basis of milligrams per square inch and the new figures plotted to produce the curve in Fig. 1. This is the standardized curve from which the hypo content of prints is ascertained after conversion to silver sulfide with silver nitrate.

TABLE II.

Hypo Contents and Transmission Densities for Test Curve.

Concentration of Thiosulfate Solution, $Na_2S_2O_3 . 5H_2O$.	Calculated Thiosulfate (Milligrams in Solution Absorbed).	Transmission Density (Capstaff-Purdy).
1 : 10,000	0.002	0.02
1 : 5,000	0.005	0.16
1 : 2,500	0.010	0.22
1 : 1,000	0.032	0.40
1 : 750	0.042	0.52
1 : 500	0.051	0.60
1 : 250	0.100	1.05
1 : 100	0.263	1.95

The technique used to obtain the standard curve was not strictly a quantitative analytical procedure and it was therefore desirable to confirm the determination of the hypo contents by analysis. Ballard and Hutchins * of the Chemistry Department in these Laboratories developed a quantitative method for the determination of hypo in photographic paper which was based on the reaction of hypo and excess silver nitrate. They found (1) that only one of the sulfur atoms in thiosulfate reacted with silver nitrate to produce silver sulfide according to the following equation:

$$2AgNO_3 + Na_2S_2O_3 + HOH \rightarrow Ag_2S + 2NaNO_3 + H_2SO_4;$$

(2) that known quantities of hypo retained by blotting paper, filter paper, photographic paper, etc., could be completely converted to silver sulfide; (3) that *p*H values within the range of 4.0 to 8.5 had no effect on the reaction; and (4) that when a sample of well-washed test paper without hypo was added to the volume of reagent used in the analysis 100 per cent. of the silver nitrate was recovered by titration. The sample containing hypo was digested in an excess of slightly acidified silver nitrate (0.001 *N*) for one-half hour at 65° F., an excess of potassium iodide added and back-titrated amperometrically. The quantity of hypo in the test sample was proportional to the quantity of silver nitrate used.

Samples of dry processed photographic prints washed for increasing times in running water were analyzed by this

* Unpublished results.

procedure for hypo. Adjacent samples were then treated in the test solutions previously described and the transmission density of the silver sulfide was determined. The hypo contents and the densities were plotted to produce a curve which practically coincided with the standard curve in Fig. 1. The greatest discrepancy between the curves amounted to 8 per cent. which is not significant. Therefore the standard curve is considered valid.

The particular advantage of the method of Ballard and Hutchins is that silver nitrate is specific for hypo when acidified to prevent reaction of silver nitrate and any sulfite that might be present.

PRACTICAL USE OF THE METHOD.

This procedure for the quantitative determination of residual hypo in photographic prints was used throughout an extensive investigation of (1) the factors affecting the removal of hypo by washing, and (2) the use of hypo eliminators reported elsewhere (10).

The method described can be simplified by adapting it to a spot-testing technique capable of determining residual hypo in prints within the range of approximately 0.05 mg. to 0.50 mg. per square inch. A series of stains produced by placing a definite volume of 1 per cent. silver nitrate on the back of each print in a series of prints having known hypo contents may be duplicated by oil or water colors and this series of stains then used as the standards for comparison with unknown print samples.

January 27, 1943.

REFERENCES.

1. TICHBORNE AND ROBINSON: "Permanent Prints, a New Plan," *B. J. Phot.*, 13: 580, 1866.
2. HARRISON, W. J.: "The Chemistry of Photography," Scoville & Adams, New York, 1892, page 414.
3. CHARRIOU, A.: "Absorption de l'hyposulfite de sodium par les papiers photographiques." Transmise par N. H. Le Chatelier (Adsorption of Thiosulfates by Photographic Paper), *Comp. Rend.*, 177: 482–484, 1923. Iodine-starch was used earlier than 1892 but all references cannot be included here.
4. JELLEY, E. E., AND CLARK, W.: "A Test for Thiosulfates," *B. J. Phot.*, 89: 714–716, 1929.

5. "Elementary Photographic Chemistry," Eastman Kodak Co., Rochester, N. Y., 1941, page 120.
6. LUMIÈRE, A. AND L., AND SEYEWETZ, A.: "Tests for Hypo in Prints after Washing," *B. J. Phot.*, **55**: 417–418, 1908; *ibid.*, **60**: 873, 1913.
7. WEYDE, E.: "On the Possibility of Increasing the Stability of Photographic Prints," *B. J. Phot.*, **82**: 376, 1935.
8. WEYDE, E.: "Über die Möglichkeiten die Haltbarkeit photographischer Bilder zu verbessern (On the Possibility of Increasing the Stability of Photographic Prints)," *Veröff. Agfa*, **V**: 181–186, 1937.
9. FREYTAG, H.: "Was für die Haltbarkeit unsere Bilder wichtig ist? (What is Important for Print Permanence?)," *Phot. Chronik*, **44**: 401, 1937.
10. CRABTREE, J. I., EATON, G. T., AND MUEHLER, L. E.: "The Elimination of Hypo from Photographic Images," *J. Phot. Soc. Amer.*, **VI**: 6, 1940.
11. CRABTREE, J. I., AND ROSS, J. F.: "A Method of Testing for the Presence of Sodium Thiosulfate in Motion Picture Films," *J. Soc. Mot. Pict. Eng.*, **XIV**: 419–426, 1930.
12. TOWNSEND, L. G.: "Proposed Residual Hypo Determinations on Film and Paper," *J. Documentary Reproduction*, **I**: 366–370, No. 4, 1938.
13. CARY, E., AND WHEELER, A. H.: "Quantitative Tests for Residual Hypo," *Amer. Phot.*, **36**: 16–18, 1942.
14. HACKL, O.: "Determination of Thiosulfate with Silver Nitrate," *Chem. Zeit.*, **47**: 266, 1923.

CONTRIBUTIONS OF SCIENCE TO AN APPRECIATION OF MUSIC.

BY

ABRAHAM PEPINSKY.

The appreciation of music implies an understanding of music in all its phases. The contributions of science in this field of artistic endeavor deal with the physicist's objective measurement of musical phenomena together with the psychologist's treatment of such data for its subjective effects on the human organism. Appreciation of music should not be defined merely as familiarity due to repeated exposure of the auditor to the "bath of sound" created by musical rendition, even though this is enhanced by biography or anecdote, or possibly the more sophisticated stage of consideration of harmonic, instrumental, and structural values. The word appreciation, unfortunately, covers a multitude of sins. To the musician, scientist and layman alike, appreciation may mean too little or too much. It is for this reason that the title of this paper refers to a *kind* of musical appreciation, rather than to *the* appreciation of music as an inclusive term.

The philosopher-scientist investigated many kinds of musical problems. Among them was the phenomenon of consonance, or musical notes sounded simultaneously, which produce an agreeable effect upon the auditor, as opposed to dissonant, or discordant tones, which have a disagreeable effect. The investigator was obviously intrigued by the question of *why* consonant sounds satisfy as well as *what* tones are involved in such musical intervals. He labored with schemes of temperament.[1] The English speak of it as "tampering" with the scale. It is really a compromise with a natural scale based on actual vibration frequencies as they are found in the harmonic series. The philosopher-scientist was aware of the desirability of providing a means of changing either mood or tonality. He strove, too, to avoid so-called "wolf-tones,"

[1] Jones, Arthur Taber, "Sound," Fig. 16, p. 71, Van Nostrand Co., New York, 1937.

which are really howling effects produced by the discordance of certain groups of tones simultaneously produced. He toyed with the possibilities of "combination tones,"[2] formed by the difference, or sum, of the vibrational frequencies of two or more generating tones or by their partials or harmonics. Organ builders and performers on the Violin learned to utilize such combination tones in a practical way. Sorge found that he could save material and space in the organ-loft by substituting two small pipes for a big organ pipe, some of which would otherwise have to be 64 feet in length. Thus, a pair of pipes a perfect fifth apart would give a resultant tone an octave lower than the root tone of the interval. The interval of a perfect fourth would offer a difference tone two octaves below the upper tone of the interval, and a major third would give the double octave below the lower note. Tartini utilized the same phenomenon to aid in teaching the true intonation of double stops on the Violin. The violinist often subconsciously uses the difference tone in tuning the open strings of his instrument. 'Cellists are less fortunate in that they cannot make use of this proof of their open-string perfect fifths because the difference tone for them would lie below the threshold of audibility[3] for such low frequencies. They check their tuning by means of harmonics, matching one half of one string length against one third of the next lower string. Following this empirical research, the scientist later found that he could analyse the complex wave forms,[4] which are the graphical representations of periodically recurrent phenomena, and he discovered that the end-organ of hearing responds to musical sounds in a like manner. This permitted him to study the artistic control of tone quality by singers and instrumentalists. Musical ornaments, sometimes called "the graces" (trills, appogiaturas, turns, and the like), were examined for their peculiar affective influences.

One musical embellishment especially, the vibrato, which

[2] Schumann, Karl Erich, "Akustik," Fig. on p. 95, Jedermann's Bücherei, Ferdinand Hirt in Breslau, 1925.

[3] Fletcher, Harvey, "Speech and Hearing," Fig. 70, p. 141, Van Nostrand Co., New York, 1929.

[4] Miller, Dayton Clarence, "The Science of Musical Sounds," Fig. 109, p. 138, The Macmillan Co., New York, 1934.

consists of a cyclic deviation [5] from a mean frequency, amplitude, or wave form, was very seriously studied by Seashore and his associates as "a measure of musical emotion." It was discovered too that short pulses of sound [6] had to be differently treated than tones of longer duration. Even "the principle of uncertainty" [7] as applied to trains of sound waves by Stewart was considered for its effect in the province of music. This principle indicates that for a given brief time interval the pitch of a high frequency note can be determined with greater accuracy than a low one, and that a note rich in harmonics is therefore more accurately ascertainable than a pure tone of the same pitch. It explains why a rapid diatonic glissando on an organ more effectively imitates a true portamento (like the slide on a Violin) when stops are employed which are poor in overtones, like the Tibia or Stopped Diapason. For sufficiently rapid execution, the uncertainty in pitch for a pure tone may actually be greater than a semitone and the ear would fail to distinguish between a true portamento and a keyboard glissando imitation. The same is true of the harp arpeggio, for when plucked at the center of the string the harp gives a fairly pure tone.

In the case of frequency vibrato the principle of uncertainty points out the relation between vibrato wideness and pitch range. Although a frequency vibrato of given rate and extent, say a semitone, may be perceptible when employed on a note in the higher registers, it would not necessarily be apprehendable on a low note. If then a vibrato is held to be a vicious practice by certain teachers, the student of Voice, Violin or 'Cello may still take advantage of the nervous response of paired antagonistic muscles under tension if the rate and extent of the resulting vibrato is within defined limits. It probably should not be admitted, but a note sufficiently off-pitch to be recognizable as such when no vibrato is present,

[5] Seashore, Carl E., *The Vibrato*, "The Psychology of Music," Vol. I, Fig. 1, p. 119, The State University of Iowa, 1932.

[6] Pepinsky, Abraham, "The Contribution of the Frequency Factor to the Psychological State of Tension," Music Teachers National Association Proceedings, Pittsburgh, Penna., Fig. 6, p. 138, 1939.

[7] Stewart, George Walter, "Problems Suggested by an Uncertainty Principle in Acoustics," *The Journal of the Acoustical Society of America*, Vol. II, No. 3, p. 325, January 1931.

may become less objectionable when a frequency vibrato is imparted to it, merely because its true pitch becomes unascertainable and the ear may adjust itself to accept the pitch actually intended. There was a time, within the memory of many in the audience, when a sensitive young Violin pupil, asking his teacher to show him how to shake his hand for a vibrato while playing sustained tones, would be told that that would come naturally when he grew older and "felt his music." This musical ornament is no longer dependent upon the emotions resulting from his first "puppy" love. It is taught—let us hope sensibly.

Probably the greatest *single* contribution to thought concerning the phenomenon of the perception of sound, however, came with the full realization that one tone might be masked [8] wholly or partially in the presence of another. This implies that the listener does not actually hear what the composer wrote and thought should be heard. The importance of this fact, especially in the field of instrumentation and orchestration, can hardly be realized by the musician who relies solely upon note symbols and expression marks.

In addition, the study of acoustics of the auditorium showed not only how to correct poor reception of music and speech and how to build desirable new auditoria, but also brought into consciousness the changes effected by the character of the reflecting surfaces of an enclosure in which music is performed by a soloist or an ensemble group in spite of their desires and efforts.

And now, to close this all too brief listing of some of the contributions of science to a better understanding of the possibilities of music, it would hardly be fair to ignore the presence of the electronic musical instruments like the pipeless organs, and the arguments leveled against the adequacy of their simulation of legitimate members of the instrumentarium, and their effect upon Mr. and Mrs. Music Public of today and tomorrow. The question will later be discussed whether or not such instruments deserve a literature of their own, rather than rehashings of compositions created for a totally different vehicle of expression.

[8] Fletcher, Harvey, "Speech and Hearing," Fig. 86, p. 169, Van Nostrand Co., New York, 1929.

It would be a great mistake to believe that theories of music are conceived first and are then followed by the practice of the art. As a matter of fact, the practical musician very often makes use of phenomena that are quite difficult to explain by rationalization. Many of the musician's readily acquired effects *still* defy analysis. But the scientist must often be satisfied with only a first approximation of the truth he strives to discover. He is limited by the nature of the simplifying assumptions necessary for a logical approach to his problem. Perhaps this is the reason he often fails to satisfy the practical musician with his rationalizations. It must be confessed, though, that it might be unwise to ask the musician to explain what he accomplishes so ably. It is much more desirable to listen to his sensitive and highly intuitive performance. This must not be interpreted to mean that the musician has no reason for that which he does so beautifully, for he develops principles of phrasing and interpretation on very logical bases. But he, on the other hand, is liable to show resentment toward objective measurement of the scientifically trained individual and expresses impatience with first approximations. If this paper were to result in a mere listing of the contributions of science, the musician might well shrug his shoulders and ask "So what?" The writer will endeavor to answer the question "So what?" by suggesting some applications of science's contributions to music, thus making for a better understanding of the beautiful art of music. The musician need have no fear of being condemned for desertion when he begins to evidence an interest in the basic phenomena underlying music. Even if the stuff from which music is made is not as mysterious as is ordinarily believed, and lends itself to analysis, the musician will discover a renewed interest in his art because of such mental stimulation. He can do his rationalizing "before or after taking" his music and still be a feeling musician in the actual act of music making.

Patterned after the art of music as practiced in the Orient as early as six thousand years ago, the speculative writings of the Greek philosophers have in turn formed a basis for many of the more detailed studies up to the present day. The disciples of Pythagoras made excellent use of his correlation

between vibrating string lengths and musical intervals. His approach to musical concordance is today still championed by the physicist and the mathematician, inasmuch as Pythagoras advised that the judgment of musical intervals should be accomplished intellectually, through the mental manipulation of numbers, rather than sensually through the medium of the ear. He explained, in other words, that consonance (or a satisfactory tone clang) is dependent upon the simplicity of the ratio of the two parts into which a vibrating string is divided. Even a thousand years later, when music became a means of expressing mysticism and religion, Leibnitz declared that "music is a subconscious exercise of the soul in simple arithmetic." He too held that the degree of consonance depends on the simplicity of the numbers comprising the ratio of the frequencies of vibration of the tonal generators.

Aristoxenus interested himself in the Pythagorean systems of music but felt ill at ease with the notion that relative consonance of musical intervals depends on intellectual judgment through numbers. He taught that the ear is the ultimate judge of consonance and dissonance; and with this radical difference of opinion began the argument which is as alive today, in spite of careful psychological research, as it was in the days of the "armchair" type of philosophical reasoning. The ultra-modernist assures the listener that the music that "stinks in the ear" today will in time become as palatable as the music of a Mozart or a Beethoven. He somewhat maliciously calls attention to the fact that Beethoven's later quartets were not understood in his day; but as a matter of fact, some of them are not fully understood today, and there are those who go so far as to say that nobody but a deaf man could have composed such stuff!

The implication that even extreme dissonance may become palatable in time is founded on the notion of a sort of conditioning process, "getting used to it." According to this school of thought, repeated exposure to dissonance seems to wear down resistance to it and the organism, sooner or later, accepts such dissonances as relatively consonant. After all, it might be asked, "Where is the line of demarcation between consonance and dissonance?" The elementary harmony student learns that the perfect consonances are those of the

primes, fourths, fifths, and the octaves, and that the major and minor thirds and sixths are imperfect consonances. All other intervals are dissonances. But "how dissonant?" asks the student. There have been numerous attempts made to arrange a scale of increasing dissonance. Some of the tests used for a measuring-stick were crude and gave no more information than did the embarrassed musician. But, in justice to the musician, it must be admitted that most consonance measuring-sticks are no more valid than are the assumptions used in their formulation.

The philogenetic argument with respect to the inclusion of ever-increasing dissonance among the musical "satisfiers" arrives at about the same solution as does the ontogenetic approach. This statement might well be tempered with the observation that the new-born child of the present decade is subjected to a truly Spartan treatment with its end-organ of hearing exposed to what comes over the radio under the guise of music. The thought is often heard expressed that the younger generation of today has a distinct advantage over its elders in that it has no inhibitions to overcome and no habits to break down. This is, of course, diametrically opposed to any notion of habituation, either through successive generations or in the maturation process of the individual.

Painting with a wide brush a panorama of the definition of consonance, there is found beyond a trivial unison the magadizing or singing in octaves (as in the voices of boy and man or in the nuptial ceremony of the ancient Greeks). Aristotle's suggestion that the other perfect consonances might well be used for singing in parallel motion found realization during the tenth century with the organum or diaphony (differentiated song) in which the accompanying voice sang in perfect fifths below the Plain Song—or Gregorian Chant. Obviously, the addition of another voice an octave below the Vox Principalis would produce a parallelism of perfect fourths with the Vox Organum. Theoretically, this was the limit of consonance until well into the 17th. century, when Thomas Morely expressed great pleasure with the effects produced by the practical musician due to the utilization of major and minor thirds and sixths, although he seemed unable to justify their satisfaction on rational grounds. It should be noted

that the imperfect consonances change modality upon inversion. *This* may have been the cause of embarrassment. A momentary glance at the Pythagorean formulation of the major third by the superposition of four perfect fifths and then reduced two octaves, as compared with the natural diatonic interval, found among the upper partials of a complex musical note, will serve to throw a bit more light on the difficulties involved in theoretical discussion. Obviously, if the superposition of perfect fifths is carried out yet further with necessary octaval reduction to the compass of an octave, the Pythagorean comma, [9] a minute discrepancy produced by the enharmonic relationship of $(3 : 2)^{12}$ to $(2 : 1)^{7}$, made it necessary to temper or modify some of the intervals to bring about consistancy in progressing from one key to another. These perfect fifths are known as harmonic degrees in the circle of keys. These modifications, or temperaments, and their limitations from an aesthetic viewpoint became a battleground for centuries. A glance at the accompanying table [10] will suffice to show the relationships of a few of the common scale temperaments bearing the philosopher-scientist's stamp of approval with respect to their degree of consonance of the intervals involved.

It would be well now to examine some of the logical approaches in measuring the degree of consonance of musical intervals. Although seemingly trivial, the Table presented by Jeans [11] offers a schedule of increasing dissonance which agrees quite well with the sense of consonance of the average listener. The term concordance implies a sounding together of two or more simultaneously produced tones. There is an appreciable difference between harmonic concordance and the melodic use of the same note symbols. Fletcher has conclusively shown that tones in combination are harmonious or discordant, depending upon the frequencies of the component tones rather than upon the pitches of the indi-

[9] Jeans, Sir James, "Science and Music," Fig. 55, p. 166, Macmillan Co., New York, 1937.

[10] Schumann, Karl Erich, "Akustik," p. 33, Jedermann's Bücherei, Ferdinand Hirt in Breslau, 1925.

[11] Jeans, Sir James, "Science and Music," p. 154, Macmillan Co., New York, 1937.

vidual tones used in a melodic manner. This effect of consonance was shown to depend upon their intensitive relationship.[12] This was demonstrated by a soft tone of 300 cycles (about D above middle C) which sounded an octave higher than a loud tone of 168 cycles (about E below middle C) when these tones were played successively like in a melody. Yet when these same two tones are produced simultaneously with the same degree of loudness as before they sound like a minor seventh rather than an octave. Melodically these tones are consonant, but harmonically they sound comparatively dissonant. Frequency and pitch are thus shown not to be synonymous terms, as was once thought to be the case. The pitch of complex (rich) tones is, however, relatively more stable than pure (overtone free) sounds. Incidentally, it was noted that rich tones sound higher in pitch than do pure tones.

Some of the measuring-sticks designed for the determination of relative consonance proved to be rather naïve instruments, failing to have significant value as tests for any but the most obviously satisfying musical intervals. The Pythagorean doctrine that "all nature consists of harmony arising out of number" which is so closely paralleled by the high regard of the Chinese philosophers for small numbers as a source of all perfection, was given a quasi psychological interpretation by the mathematician Euler. He explained that "the human mind delights in law and order and so takes pleasure in discovering it in nature." Euler thought that the smaller the numbers required to express the ratios of the two frequencies in an interval, the easier it is to discover this law and order and, therefore, the pleasanter it is to hear such sounds. But the mathematician desires something more quantitative than such a simple approach. Euler suggested the expression of the frequency ratios of a chord by the smallest numbers possible, after which it was only necessary to find the smallest number into which all the numbers comprising the frequency ratios could be divided exactly. This resultant number would then give a measure of consonance of the chord; that is, the smaller the number the more consonant the chord.

[12] Snow, William B., *The Journal of the Acoustical Society of America*, Fig. 6, p. 17, Vol. 8, July 1936.

A few simple examples will serve to clarify Euler's hypothesis. In order to understand the results of such an approach to the study of concordance, it will be advisable first to make use of the frequencies defined by the natural diatonic scale derived from the harmonic series of a rich musical note. It should be understood that Euler's concept was in no way limited to so orderly a scale. On the contrary, he hoped even to consider the effects of temperament on consonant intervals. Now, for the sake of practice, try this test first of consonance on a simple diad, a two-tone clang. Take, for example, a perfect fifth and a perfect fourth having the ratios 2 : 3 and 3 : 4. The smallest numbers into which each pair of numbers can be divided are 6 and 12 respectively, which is therefore interpreted to mean that the perfect fifth is more consonant than the perfect fourth. The musician shakes his head approvingly, although the perfect fourth is merely the inversion of the perfect fifth, standing on its head, as it were. But, as a matter of fact, most musicians do not like the tonal effect of an isolated perfect fourth anyhow. Next, to proceed to another step beyond the obvious simple diads, there will be found a choice in favor of a minor chord over a major, as in—c : e flat : g : c′ (10 : 12 : 15 : 20) compared with c : e natural : g : c′ (4 : 5 : 6 : 8), even though the latter is represented by smaller numbers, Euler would explain that the numbers of the minor chord could all be divided into the number 60, whereas the major chord's numbers would require 120 as the smallest number into which they could be divided exactly. This might *still* satisfy ordinary musical criteria, if the context in which such chords might be found were ignored. Jeans points out, however, that if a seventh chord were constructed by replacing the c′ with a b-natural in the simple major chord, the comparatively dissonant seventh would pass unnoticed according to Euler's measuring stick. The number 120 could still be used into which to divide the appropriate numbers 8 : 10 : 12 : 15 for c : e : g : b-natural. This type of rationalization might give some gratification to the modern theorist. It will later be shown, however, that Helmholtz offered more rigorous psychological criteria for dissonance created by the close approximation to consonant intervals in isolation. It must be admitted that Euler's test fails beyond the degree

of dissonance where a measuring-stick might well prove most useful.

Jeans becomes a bit playful in showing how the Euler criteria might be applied to make even a major chord (4 : 5 : 6 : 8) more satisfying. He advises omitting first the major third, in which case the divisible number would be reduced from 120 to 24. Then if the perfect fifth were taken out and the frequency ratio reduced to its lowest terms, the number 2 would suffice. If the octave were dropped only the number 1 would be necessary, and the ideal consonance would be obtained by sitting in utter silence! This is perhaps not such a poor solution after all.

Jeans really thinks of consonance differently. He feels that a healthy being finds pleasure in the exercise of his faculties. He likens the various degrees of pleasure in exposure to musical tone clangs to the working of crossword puzzles or to mountain climbing, "within limits," he says. G added to C makes for greater interest, as would also the note E, says Jeans, but a C-sharp added would be just too much! This expresses in a naïve manner the need of a desirable balance between the possible monotony of too consistent satisfiers, and mild annoyance, to tickle the musical palate. But this again should take into consideration the musical context in which an interval or chord appears, rather than an attempt to treat isolated tone clangs.

D'Alembert, another mathematician, chose to avoid the arithmetical approach to the problems of harmony and completely ignored the metaphysics of the older philosophies. He based his opinion concerning harmony on Rameau's speculations concerning the sounds of Nature. His argument was simple in that he found a musical interval consonant if it agreed with the harmonic scheme of Nature, from which the diatonic scale is taken, it will be remembered.

Helmholtz applied the techniques of experimental psychology to what he termed the degree of "rawness" [13] of a tone clang; rawness as a criterion of dissonance. His graph of dissonance based on this criterion has become a classic and is meaningful today as ever. Having obtained these results,

[13] Helmholtz, Hermann L. F., "Sensations of Tone," English Translation by Alexander Ellis, Figs. 60, A & B, p. 193, Longmans, Green & Co., London, 1912.

Helmholtz sought for an explanation of the data obtained He based his speculations on the fact that the upper partials of the complex notes defining a musical interval produces beats with one another depending upon their proxmity. The next step was obviously to obtain criteria [14a] of rawness produced by such beats as a function of their rate and the position of the tones involved in the area of the audible frequency range.

The notion of elimination of the sense of rawness in an interval to insure its being a satisfier rather than an annoyer soon directed Stumpf's [14b] attention to the fact that a large percentage of the population, musical and otherwise, heard consonant diads comprised of pure tones as a single note. (Credit for the terms "satisfier" and "annoyer" should go to Thorndyke.) More dissonant combinations failed to so affect the listener. He thus found a means of ranking consonance by the percentage of auditors who heard only a single note instead of the two actual generating tones. The next step in psychological reasoning began to utilize the idea of oneness, fusion, or blending of a tone clang as a criterion of consonance. Seashore was so convinced of this attribute of consonance, that he used consonance as one of his six measures of musical capacity, thus defining the innate musical talent of a child. It was an uphill and bitter fight, however, lasting from 1918, when the first recordings were released for the school testing program, until 1938, when the new series of tests and measurements appeared, in which the consonance test was omitted entirely in favor of a test of timbre or tone quality. "A rose by any other name smells just as sweet," however, and even though consonance is no longer stressed as one of the six musical "senses," timbre discrimination answers much the same innate capacity requirements. It is interesting to note that the most violent opponent to the inclusion of the old consonance test in the battery of measurements was the practical musician, who refused or was unable to follow instructions. He could not answer in terms of "better or worse" on the basis of oneness, fusion, or blending of a tone clang.

[14a] Schumann, Karl Erich, "Akustik," p. 100, Jedermann's Bücherei, Ferdinand Hirt in Breslau, 1925.

[14b] Ibid., page 115, § 26.

He so readily recognized the conventional musical intervals, that he refused to commit himself in stating a preference for a minor to a major sixths, or vice versa, for example. To him they were equally consonant, depending entirely upon context for any differentiation. This is a reasonable explanation of his attitude toward consonance, but it does not excuse him for his inability or unwillingness to play the game according to the rules laid down. It was a difficult test to administer to younger children. The music teacher who gave the test did not quite know what was required, and so the youngster's response offered data that had but little statistical validity or reliability.

Out of the ashes of the consonance test arose the phoenix *timbre*. It was hinted above that the sense of timbre might well be substituted for the sense of consonance as Seashore originally conceived it. This was brought to light while administering the new timbre test, and further psychological experimentation was inaugurated. The new categories of response "same or different" removed the atmosphere of antagonism engendered by the "better or worse" in the paired comparisons of the old measures. It is interesting to note by what criteria the subjects make their judgments. Many obviously have no notion of tone quality as the musician is trained to perceive it. Of course, it must be admitted that the increments of difference in timbre demanded by the Seashore timbre test are much finer than that which distinguishes an Oboe from a French Horn or a Violin from a Trumpet. No conventional instrumental qualities are included in the test, so that the musician's training offers no advantage over the layman, except for power of concentration on such sound effects. The subjects used in the more detailed experiments were found to use not only an adjectival approach, such as brightness, dullness, shrillness, sonorousness, "tinnyness," and the like, but some discriminated by a sense of pitch, that is, the brighter, richer sounds appeared higher in pitch than the duller, purer tones. Others discerned a difference by means of loudness discrimination, inasmuch as the richer tones contained upper partials that impinged on a more sensitive portion of the basilar membrane of the inner ear. Others responded to a sense of density and volume, density in the

sense of compactness, and volume, its antithesis. It was most interesting to have these correlations so nicely brought out. If there were time, some of these could be embellished to advantage, but it will have to suffice to refer to them now and again in other connections.

One of the most serious limitations placed on research in the field of sound, from the point of view of the musician, is the obvious necessity for the simplifying assumptions with respect to the use of pure tone, because pure tones or sounds free of overtones are relatively rare in music and, indeed, in nature. Certain bird calls, the human whistle, and a carefully struck tuning fork are some of the very few examples to be found. The extreme registers of some musical instruments are quite free of upper partials and therefore also quite pure.[15] It seems incongruous, for instance, to think of the highest notes of the Tuba[16] as being pure, but they really are, surprisingly so in the hands of an artist. Does a composer recognize this fact? Some do from experience, but most of them think of the Tuba as having a distinctive quality. Its quality depends upon the relative strength of its overtones or harmonics (as they are sometimes called) and it is readily seen from the spectrum that it changes quality in its various registers and even from note to note. This is especially true of the Violin,[17] where the slightest change of position of the stopping finger on the string changes the quality as well as the pitch. It is thought by some that the subconscious urge for a vibrato on this beautiful instrument is due to a desire to smoothe out these quality differences in appropriate phrases. In teaching the instrument for control of desirable timbre, the very interesting adjectival approach referred to before seems to be the only means of describing the tone quality. This makes for a very intriguing psychological study which is as yet in its infancy.

A rough comparison of the wave forms[18] and spectral components associated with the various musical sounds gives evi-

[15] Seashore, Carl E., "The Psychology of Music," p. 195, McGraw-Hill Book Co., New York, 1938.

[16] Ibid., p. 197.

[17] Ibid., p. 216–217.

[18] Miller, D. C., "Science of Musical Sounds," Figs. 148, 149, p. 200; Fig. 134, p. 196; Fig. 154, p. 205, Macmillan Co., New York, 1934.

dence of definite characteristics which may be said to define tone quality. D. C. Miller's pioneer work in the science of musical sounds brings out this fact in a most interesting manner to the attention of the student interested in such things. The analyses of such graphs portray definite instrumental and vocal tones at a single frequency and intensity level. The oscilloscope, with its neat visual presentation of wave form, can be sadly misused in the hands of a charlatan. It is told that some "up-to-date" studio teachers actually attempt to make their students conform to the presentation of an ideal wave form picked up from the recordings of famous artists' renditions. One is reminded of the picture of a flower or vegetable on a five-cent package of seed which is attached to a stick at the end of a row so that the little seedlings learn to know what they should look like when they grow up! The difficulty in using the oscilloscope in this manner lies in the fact that the wave form changes with the phase relation of the components. D. C. Miller's analysis[19] shows the phases of the components of an organ pipe tone. At a given instant, it shows the part of a cycle in which the wave finds itself at that instant, relative to some arbitrary reference point. Such phase relationships are seldom under the control of the performer, and it is well that, except for great intensities, phase plays a lesser role in its effect on tone quality than do the relative harmonic intensities. To the expert who has made many tonal analyses may be granted a considerable knowledge of that which a graph implies, but this is certainly beyond what can be expected of the average teacher who invests in such a piece of laboratory apparatus. It is only just to call attention to the fact, however, that instruments of the oscilloscopic family have been advantageously used in the training of the deaf in the production of desirable vowel sounds, of which they could otherwise have no possible conception. These vowel sounds possess wave forms which differ from one another, just as one instrument from another, sufficiently to characterize them; but it must be reiterated that such wave forms are not unique. In fact, it would be quite difficult to reproduce a wave form exactly with the voice, or an instrument controlled by hand or lips.

[19] Miller, D. C., "Science of Musical Sounds," Fig. 98, p. 125, Macmillan Co., New York, 1934.

With apologies to Dayton C. Miller, the question of the influence of phase relations of the partials of a complex musical note is being mentioned for its importance in aural reception. After all, the organism's end-organ of hearing must needs play an important role in the perception of aural phenomena. Miller referred to an interesting photograph [20] due to Helmholtz of the change from down-bow to up-bow on the Violin. The graph indicates the reversal of phase of all components of the violin tone by 180° as the bow changes direction. Now, as an interpretation of this phenomenon, Miller calls attention to the fact that although the change of phase is obvious in the graph, the ear perceives no difference in tone quality, and he, therefore, concludes that phase relationship between partials plays no part in the recognition of tone quality. Now, as a matter of interpretation of data in general and the effect of subjective evaluation of objective measurements in particular, it may be mentioned that any sensitive violinist recognizes a difference in tone quality between an up-bow and a down-bow, and therefore the graph actually corroborates what the ear perceives, which means that phase does play a significant part in quality differentiation. Naturally, the violinist, or any string player for that matter, has also to contend with intensitive control as he changes bow direction, but such factors are readily discernable as amplitude changes primarily and are so discovered in the graph. Even with this kept quite constant, the reversal of phase still takes place and is indeed quite recognizable to the trained ear.

Firestone [21] and his associates showed that a change of phase alters the loudness of a harmonic and of the total experience. If the fundamental is a low tone, an appreciable difference in quality is noted. An adjectival qualification was reported in the case of the phase relation giving minimal loudness. The quality was characterized by smoothness; whereas the opposite phase, leading to maximal loudness, bore with it a rough and dissonant element. Lewis [22] showed that the phase relations between the harmonics had a very decided effect on the perception of the difference tone.

[20] Miller, D. C., "Science of Musical Sounds," Fig. 144, p. 197, Macmillan Co., New York, 1934.

[21] Stevens & Davis, "Hearing," Fig. 86, p. 205, John Wiley & Son, New York, 1938.

[22] Ibid., Fig. 87, p. 206.

The harmonic analysis of musical tones implied in the foregoing discussion is based upon an important mathematical principle evolved by Baron Fourier in the early part of the nineteenth century. Fourier's theorem may be stated simply: Given any curve representing periodically recurrent phenomena of definite wave length, the same curve may always be reproduced, and in one particular way only, by compounding simple harmonic curves of proper amplitude and phase. These curves may be infinite in number and they have the same axis. The wave lengths are successive aliquot parts of the fundamental length, that is, 1, $\frac{1}{2}$1, $\frac{1}{3}$1, and so forth. The curve, such as any of those herein discussed, may have any arbitrary shape whatever, including any number of straight line portions; but the ordinate of the curve must always be finite and the projection of successive points on the curve must always move in the same direction. The axis represents time, and "Time marches on." Wave-form and timbre are respectively the physical and psychological expressions of tone-quality. Ohm definitely stated a law of tone-quality some time before the middle of the nineteenth century (as a matter of fact, just one hundred years ago). Based on this law some thirty years later, was devoted the beautiful research in "Sensations of Tone" by Helmholtz. The law may be paraphrased to read: Musical tones are periodic. The human ear perceives pendular, that is, simple harmonic motion, as simple or pure tones. All kinds of tone-quality are due to particular combinations of a larger or smaller number of simple tones. The motion of the air that corresponds to complex musical tones, singly or in composition, is capable of being analyzed into a sum of simple harmonic vibrations, and each of these simple vibrations corresponds to a simple tone which the ear may perceive as a pure tone.

To recapitulate, the study of musical sounds obviously deals largely with the consideration of their complex nature. The components are the partial tones, and the partial with the lowest frequency is known as the fundamental. The others are the overtones. It is possible for one of the partials to be predominant to an extent that it assigns the pitch of a complex note to it. This is characteristic of bell tones especially. At times, too, the real fundamental may have no real

physical existence, or it may be of too low a frequency and too insignificant an intensity to be perceived by the ear. Yet the ear supplies such a fundamental by means of beats and difference tones, as the result of the overtones in combination. It is spoken of as a difference tone if the partials generating it are of considerable and comparable strength; otherwise they are known as beats, and consist of a periodic waxing and waning of intensity. Overtones that have frequencies which are the exact integral multiples of the frequency of the fundamental are called the harmonics, otherwise it would be best to speak of them as inharmonious partials.

While speaking of the influence of tones of great intensity in reference to the generation of difference tones, it would be well to elaborate on the effect such intense sounds have on others in their presence. It seems almost trivial to call attention to the obliteration wholly or partly of one sound when it is accompanied by another. A tone is said to produce masking when it raises the threshold of audibility of a second tone. The measure of masking is in the number of decibels (to be explained) that the threshold of the masked sound is elevated in consequence of the presence of the masking sound. The decibel (one tenth of a bel) is a unit of measure of power originally used in the field of communication. The number of decibels denoting the ratio of two amounts of power is ten times the common logarithm of this ratio. It is convenient to think of the decibel also as a unit of measure of the sense of loudness, being for the average ear the least incremental change of intensity recognizable as a change in loudness. This logarithmic unit of loudness obeys the Weber-Fechner law, ($\Delta L/L$ = constant), for sensation, but attention must be called to the necessity for a consideration of the reference level used for zero db. The sensation level indicates the number of db of a sound above the threshold of hearing for that frequency, whereas the loudness level for a given tone is defined as the intensity level of a thousand-cycle tone which sounds equal in loudness to the given tone. It is unfortunate that these terms are often confused in the literature for both the musician and the physicist.

With this very brief reference to the meaningful terminology used by those who interest themselves in the borderline

field between music and science, it may be illuminating to apply some of these masking effects to a simple problem in instrumentation or orchestration. It may serve to furnish at least a partial answer to the question of why the arranging of musical sounds into meaningful patterns is more than a mere mechanical building of chord structures according to prescribed formulae.

Instrumentation is concerned primarily with the study of the possibilities and the limitations of musical instruments and the production of desirable sound effects, whereas orchestration may be thought of as consisting of the sensible combination of instruments designed to enrich the colors of the musical palate. There is now considerable knowledge at hand concerning musical instruments in their differentiated registers and at various intensity levels. Physically, furthermore, instruments in combination can be examined for the relationships of their overtone structures. But experience shows that instruments in performance together are not heard in quite that way. The spectral analysis of even a single instrument differs from that which is anticipated by the owner of a well trained ear. Wegel and Lane's researches in the field of masking effects serves to offer a clue to the psychological point of view that the relative strengths of the partials must be affected by a masking of the higher partials by the lower ones, and the weaker by the stronger overtones, even if the effects of phase relationships are disregarded. The effects of one instrument upon another within an ensemble and the quality of the composite tone produced, has been empirically explored by the great composers. Trial and error were the means utilized, however, and reasons for the existence of intra- and inter-instrumental relationships have never been sufficiently investigated in a scientific manner. An attempt will here be made in a naïve venture in orchestration to indicate the possible effects of masking on the tone quality of one instrument in the presence of others. Consideration will be given to the fact that strong partials of one instrument influence the response to the composite tone of *that* instrument, as well as the partials comprising the combined tones of other instruments in the ensemble. The Gestaltist's point of view that "the whole is more than the sum of its parts" is supported in

this attempt to show that an ensemble of instruments in performance is perceived as something quite different from that which the mere physical addition of partial intensities might lead one to expect.

For an arbitrary choice of instruments with relatively simple spectra, and which are sufficiently familiar in timbre to most listeners, an ensemble consisting of a Cornet, French Horn, Trombone, Baritone, and Tuba will be chosen. These instruments will be made to simulate the presentation of a very simple chord, that of the tonic of B flat major in various settings and degrees of dynamics (that is, intensity). The procedure will consist of an investigation of the complex tone produced by each instrument independently to determine the influence of the inner relationships between their partials on auditory sensation. Then the results for each instrument will be combined to ascertain the cumulative effects when all five instruments are sounded together under conditions of three degrees of dynamics, that is, piano, mezzoforte and forte; and a number of arrangements of the tones of the chord. Use will be made of Sivian, Dunn, and White's data with respect to absolute amplitudes and spectra of the instruments under consideration. Besides this, the phono-photographic spectral analyses of these same instruments developed by Seashore and his associates will be utilized. Quite arbitrarily 40 db will be chosen to signify a mezzoforte (medium loud) level for an average reference intensity, as is customary by the communications engineer. A sensation level of 60 db will then be designated as forte (loud) level, and 20 db a piano (soft) level.

The assignment of the actual sounding notes within this arbitrarily chosen chord will be as follows: the Tuba (the conventional one in E flat) will sound $B\flat_{14} = 58$ cycles per second; the Baritone is to sound an octave higher, $B\flat_{26} = 116$ c.p.s.; the Trombone will be given a note an octave plus a major third higher than the Baritone, $D_{42} = 290$ c.p.s.; The French Horn is to have the fifth of the triad, and is therefore a minor third higher than the Trombone with $F_{45} = 348$ c.p.s.; and the Cornet will have the highest tone, $B\flat_{50} = 464$ c.p.s., two octaves higher than the note of the Baritone. Seashore's associates offered data that indicate not only a wide variation

in number and strength of the partials between instruments, but also a great variation in the strength of the overtones between the playing of piano and forte on a single instrument. Inasmuch as the Seashore data are limited to definite tones of the instruments, it will be seen that the chord was chosen and notes assigned so as to avoid confusing substitutions as far as possible.

The next step is to make a comparison of total average pressures produced by each instrument. For this purpose, the computations made by Sivian, Dunn, and White were utilized. Since no data were available for the Baritone, it was experimentally established that the wave-form for the Trombone could be used with good approximation. Inasmuch as Sivian, Dunn and White's measurements involved the BB♭ Tuba instead of the E♭ Tuba, and was taken at a distance of five feet from the source of sound instead of three feet, as with the other instruments, computation based on the inverse square law involving these relative distances had to be made to obtain the proper pressure, allowing also for the substitution of the E♭ for the BB♭ Tuba. Because these pressure measurements of the instruments represent the total average pressure obtained in playing a group of musical compositions covering all gradations from pianissimo to fortissimo, the figures obtained represent an average of the intensity range. And since 40 db is taken to represent an average degree of intensity level for physical measurements in the field of communications, it may be assumed that the pressure levels established by Sivian, Dunn and White represent the requisite pressures for the production of an average tone in auditory sensation. It is then only necessary to translate these findings in terms of the 60 db and 20 db levels.

Pressure values for each instrument now have to be converted into pressure per partial residing within the complex tone for the higher and lower sensation levels of this study. This is readily accomplished by plotting the information obtained on the conventional graph representing the threshold of audibility and then translating the sound pressure, measured in bars, into sensation units.

With the relative partial strength of each instrument now translated into sensation units at the piano and forte levels,

it is possible to proceed to the study of the masking effects of the partials of the individual instruments by applying the data obtained to Fletcher's graphs adapted from the Wegel and Lane shifts in threshold values throughout the musically significant frequency range. Fletcher further indicates that the total masking effect produced by a complex note is equal to the sum of the effects produced by each individual component, and also calls attention to the overlapping effects of the components of a complex tone. It is thus possible to predict the cumulative masking effect when two or more instruments are sounded together, because of the overlapping effects of strong components lying within the composite tone.

Because of the extreme sensitivity of the end-organ of hearing for a definite region of the frequency range and because of the threshold shifts for some of the components as a result of the masking effects, the perception of some of these instruments is very surprising in the light of the physical constitution of the tones under consideration. For instance, at the forte level the Tuba's partial, 116 c.p.s., gives a sensation level of 72 db, with a correspondingly great masking possibility. The masking effects between the components of the Baritone note, $B\flat_{26}$, are very complex, with the result that the 4th, 5th, 10th, and 13th partial are masked out completely with a corresponding weakening of some of the remaining tones. In the Trombone the 6th partial is masked out completely and the remaining partials weakened in sensation. The French Horn and Cornet tones likewise suffer great modification. It is for this reason that one finds it difficult to reconcile the adjectival approach of the musician with the knowledge of the spectral analyses of musical tones.

With the results of the calculations of the masking effects for each instrument, the next step is to combine the instruments, adding one at a time until the ensemble is complete for each of the sensation levels under consideration. At the forte level the Tuba is found to influence strongly the tones of the other four instruments represented in the chord, but the Baritone's upper partials, $C_{76} = 2088$ c.p.s., and $D_{77} = 2204$ c.p.s., remain practically unaltered in strength and produce a distinct beating effect with a resultant quality of roughness.

This is not apparent in the Baritone's tone when the sound comes from the solo instrument.

There are nine components ultimately represented in the sensation produced by the five instruments at the 60 db level, with the octave above the fundamental predominating over the remaining tones of the chord. There is unfortunately not sufficient time to go into the psychological experimentation which was found necessary to prove the introspective reaction to such a quality. It was characterized by the word "rich" by the observers who gave their time and effort to the experiment. Others spoke of the combined chord as being "bright." This latter adjective was found to be a probable result of the duplication and resultant prominence of the octaves within the overtone structures.

At the piano level (20 db) this same ensemble of instruments, playing the same chord, offered the sensation of a simple triad $B\flat_{26}$, D_{42}, F_{45} and some of their octaves. The resultant tone quality was said to be "smooth." Some of the observers, however, indicated a degree of "brightness."

Another setting of the same chord called for the Cornet at a forte level, as in a solo, with the four remaining instruments playing piano, as in an accompaniment. An examination of the components of the perceived tone of the ensemble showed that the bright, rich quality of the Cornet tone is practically unaltered by its association with the others, but that the quality of the accompanying instruments is altered a great deal in the combining process. The tone D_{42} of the Trombone and F_{45} of the French Horn are so weak that they do not seem to affect the sensation produced by the instrumental chord to any appreciable extent. The Trombone and French Horn tones would probably have to be played mezzo-forte rather than piano in order to produce a better balanced accompaniment for the solo instrument. A routined orchestra or band conductor would be expected to make just such an adjustment.

When the French Horn is presented at a solo level with the other four instruments playing piano, the Trombone is masked out completely from sensation. Also the Baritone contributes but little under these circumstances. On the other hand, the

Cornet retains its identity fairly well. The chord sounds musically unbalanced, however.

With the Trombone raised to the solo level the tone quality is said to be bright but badly balanced.

The combined ensemble, when the Baritone is given the solo voice, affords an unusual array of overtones with a prominent fundamental, and the tone is described as rich. The overtones C_{76} and $D\flat_{77}$ are sufficiently prominent to produce a sensation of roughness. A better balance was secured by raising the level of the Trombone and the French Horn to a mezzoforte level.

A most interesting condition is revealed when the Tuba takes on solo proportions, inasmuch as the tones which are readily perceived depart from the prescribed chord of the tonic of B♭ major played by the ensemble. No simple triad remains from the retinue of the combined partials after the phenomenon of masking takes its toll. There remains only a duplication of octaves with a single fifth in the upper register. In this setting the French Horn does not seem to influence the tonal sensation in any way, and might just as well be omitted from the ensemble.

When the Tuba and Baritone are played an octave higher, and all the instruments are permitted to play forte, the fundamental of the Tuba predominates in strength over the remaining components in the chord. The difference in strength is so vast that the chord again sounds poorly balanced. In this chordal position the Tuba should obviously be reduced to a mezzoforte. When this new chord setting is played at a piano level, a well balanced chord results, and the quality is judged as smooth, with the fundamental prominent. This was judged to be the most satisfying setting.

If the Cornet is elected to play forte in this setting, the other instruments with the exception of the Tuba will not be heard. When the French Horn is raised to the forte level, only the Tuba, French Horn and Cornet seem to be represented. The resultant quality is described as rich. When the Trombone is played as the solo instrument of the ensemble, it influences the resultant quality greatly. The Baritone and French Horn disappear entirely, and the Cornet contributes but little. The chord sounds badly balanced.

Raising the Baritone to solo dimensions in the ensemble discovers only the Tuba, Baritone and Cornet to be present. The Trombone and French Horn could just as well be omitted. A peculiar chord is heard. The $B\flat_{26}$ is duplicated in four octaves with a strong F_{69}. The quality was judged as being very bright. And then, when the Tuba is graced with the solo level, all of the tones of the other instruments are reduced to below threshold value. Only the Tuba's components appear in the final analysis.

The results of much painstaking calculation have been all too briefly sketched, together with a few remarks on the subjective responses of listeners to the quality of the various chordal settings and intensities. Experienced instrumentators know much of this from trial and error and reference to the great works of the past. Conductors are able to adjust many faults by changing the relative intensities during rehearsal for performance. It is important to discover, if possible, why some arrangements sound better than others. The results obviously show that chords do not necessarily sound as they are written. In many instances instruments might well be omitted entirely. In many cases the notes of the chord must be reassigned to different instruments in order to secure proper balance. Examples from the literature, as in the Schumann symphonies, offer excellent laboratory experimentation for the consideration of just such problems as have been set up in this limited discussion. Consideration of such problems in the light of the foregoing data would at least tell the composer and arranger what *not* to do, and give pause to the young creator lacking orchestra training. It must be admitted that the amount of generalizing which can be done from these results is indeed very slight if one attempts to tell the composer what to do. In the meantime, the musical world continues to be grateful to the experienced conductor for his ability to fix things during rehearsals, but this need not discourage rationalizing in an effort to create some order out of chaos.

In all the above discussion of quality of tone, it must not be thought that there is one and only one best quality, for the history of music indicates that taste in tone quality, like style in dress and foods, is subject to continuous modification.

Although this process may take on a cyclical pattern, each change brings with it an element of newness and difference. Growing out of these alterations and favoring them is a tendency among younger generations to deprecate the musical ideals of their elders.

This fact of change can be demonstrated by a review of the musical implements which have obtained throughout the life of man. Unfortunately, insofar as vocal-tone quality is concerned, there have been, until quite recently no records other than those of a descriptive nature, but such description is to some extent objectified by consideration of the musical instruments of particular periods. Research workers of this generation can well express a debt of gratitude to musicologists like Curt Sachs who, as a curator of a museum of ancient instruments, made every effort to keep an extensive collection of musical instruments in playable condition so as to give the listener an excellent insight into the quality of tone as well as the formal outline of the music of various periods. That such qualities became fashionable again is evidenced by the fact that the Michael Praetorius organ of pre-Bach days was installed as an integral part of many of the world's great organs of a generation ago. Many of the pre-set stops of the modern electronic instruments are designed to simulate the nasalized, strident effects of the music of the polyphonic era. Again, the trend in the voicing of the legitimate pipe-organ solo stops echoes the desire for the timbre of rich mixtures in registration. This is quite contrary to what was considered desirable in the late neo-romantic school of organ playing. On the other hand, Mr. and Mrs. Average Public of today are once again showing a strong predilection for suppression of high frequency intensities on their radio and phonograph, utilizing the "low-tone control" to eliminate the penetrating, irritating effects of the "highs." This psychological reaction puts a distinct damper on the efforts of the electrical engineer to give the auditor what is known as "high fidelity." The manufacturer of phonograph records has evidently realized for some time that the consumer is content with an extreme upper limit of approximately 5,000 c.p.s., although this is a far cry from high fidelity. The same argument governs the efforts of the communications engineer, both telephonic and

radio. This approximation is obviously satisfactory to the buying public, and more than such an approximation of the real music would be but a waste of effort and materials.

The lesson learned from the electrical engineer during the past few years offers a fine measuring-stick for evaluation of acceptable tone quality. Experimentation with novel and rich tonal effects is, however, being carried forward. The past decade has, for example, revealed a number of electronic machines simulating other musical instruments, generally using the pipe-organ as a prototype. Most organists, however, resent such innovations because the adaptation of traditional "stops," representing various instrumental effects, do not sound sufficiently like those of the pipe-organ. One need have but little patience with such an attitude because the organist's traditional stops themselves offer only a first approximation of the instruments they represent.

Musicians and laymen have, in general, however, been greatly intrigued by the possibilities of these new music-makers. One organist, for whom the musician has great respect, expressed himself very sensibly, saying that "these machines are on their way in, not out, and we had better take an interest in them and understand their possibilities." Too many of the ordinary "garden-variety" of organists attempt to play the literature of the pipe-organ on these electronic machines, with no knowledge of the capacities and idiosyncracies of these instruments, and thus without any notion of the adaptation of the literature designed by the composer for quite a different type of mechanical apparatus. Such attempts can only result in prejudice against these new instruments. To do justice to such novel possibilities, if the older literature is to be played at all on these machines, the music must naturally be reconceived, that is, rearranged. But if the composer is sufficiently stimulated, he will now create with the new instrument in mind, instead of "rehashing" conventionally accepted music. So-called arrangements are at best merely makeshifts and are often referred to as *Derangements*. Such adaptations unfortunately produce stagnation, to the detriment of possible advancement, and can only result in discouragement of creative effort. The organist becomes quite peevish, also, with the epidemic of orchestral transcrip-

tions of his cherished literature; and is perhaps justly indignant, in spite of the luscious bath of sound produced. The effort of the psychologist in the effects of music is obviously still in its infancy.

The same seems to be true of the repeated efforts made by pianists, organists and orchestral arrangers to bring out more fully the marvelous musical intentions of Johann Sebastian Bach in the Chaconne for solo violin, unaccompanied. Certainly every fiddler, no matter how capable, has had the feeling that this magnificent work is beyond the vehicle for which it was conceived, not technically but interpretatively; but the curious fact remains that it is evidently beyond any vehicle yet tried for the expression of this great music, and the Violin does the Chaconne justice if any of the instruments do. The musician does not seem to have solved the problem. Can the psychologist?

Until very recently, the ambition of the wind band seems to have been to sound like an *organ* or like an *orchestra*. Perhaps it was a *desirable* expression from an organization in its growing pains; but again it must be confessed that in spite of the excellent training given to a countless number of young people, the end results became either tiresome or grotesque. The *de*rangers seemed only to follow some rule-of-thumb schedule of instrumental substitutions. In an instrumentation class the writer indicated impatience with such a trivial solution of the problem by referring to such arrangement as or-*ca*stration. The laugh which followed encouraged a further mixing of metaphors, in which the results were likened to the performance of the medieval castrated singers, who with all their wonderful vocal technique, evidently lacked the musical virility of their organically *sounder* fellow beings. Not until the wind-band is able to stimulate worth while composition for its own distinctive interpretation can it rise above the plane of mere pageantry.

The modern electronic musical instrument is no doubt going through a like period of growing pains. Commercialism has been responsible for the wide distribution of these instruments in the hotels and dance halls for the novel effects produced with the dance band. It is hardly to be wondered that the church music committee is liable to vote against the inclu-

sion of this "novelty" instrument in the religious service. The "three dollar a Sunday" organist, it is feared, might pull the wrong lever or press the wrong "preset" stop! The issue must be squarely faced in the search of a solution of the problem. There is truly an embarrassment of riches in some of the electronic instruments, which in the hands of an ill-advised player would be much like a loaded blunderbuss in the hands of a child. Modern instruments offer opportunity to create many new qualities, but if performers on these instruments are content merely to imitate tone-qualities with which the public is already familiar, there *is* and *will* be much to apologize for; because even with the seeming embarrassment of riches implied by the huge range of intensities and frequencies available in the electronic-instruments, there are definite limitations imposed by the design of the machines. The possibilities are either definitely fixed and constant, as in the pipe organ, with regard to the relative intensities of the overtones of the complex note, or again flexibility is only to be found in a limited selection of the harmonic series.

It is obvious from analysis of the factors which contribute to artistic effects in the interpretation of music that there must be a conscious control of timbre in voice and instruments by the artist. An instrument with fixed relations among the overtones must then be dependent merely upon variation in intensity. The interpretive artist as well as the composer must also think in terms of the gross differences in the various registers of voice and *instrument*. Furthermore, it was found that many of the conventional instruments offered definite variation in tone quality from note to note even in the same register. Then, too, the artist consciously makes use of possible transients, some of them in the form of noisy by-products in attack and release and within the duration of the tone for the control of expressive values. And it is well known that one of the greatest factors in display of emotion in musical performance is the deviation from the steady-state tone by means of the vibrato, intensity tremolo and cyclic changes of timbre. These three variants may be combined in the general term of "sonance" so aptly conceived by Seashore's associates, but which are individually controlled by the interpretive artist. But it must be remembered that an analysis of these

factors in terms of average rates and extents or other characteristics does not offer a true analysis of conditions necessary for artistic effects. An instrument, therefore, which offers any of these factors in terms of such averages definitely tends to limit freedom of expression. Seashore's coworkers give fine evidence in their phono-photograms of the wide range in variation of such elements of expression, but choose to interpret their results in terms of the average rates and extents of the vibrato rather than to carry out a detailed analysis to obtain the meaning of the rate of change of these variants. This quality is known to be not merely dependent on the relative intensities of the overtones of the complex note. The ear offers tones not intended by the composer, even when only a pure note is wanted, if the intensity is sufficiently raised. This is complicated by tones in combination. Phase relationships and their effects have already been mentioned. Control of fine increments of frequency change associated with what is known as tendency tones offers a further heightening of interpretive effects. This is commonly known among musicians as psychological intonation.

Manufacturers of modern electronic instruments have by no means attempted to exhaust the known possibilities at their command. Any number of patents will probably never be commercially utilized. A sufficient approximation to satisfy the buying public is obviously the temporary order of the day, but competition and the ever-increasing appreciation of artistic values will tend to further stimulate inventive genius. The new instruments, with the manufacturer's choice of tonal qualities and resultant psychological effects upon the buyer, beautifully reflect the trend of current opinion as to what is today acceptable in tone quality, for it is deemed wise to give the public what it thinks it wants.

Serious psychologists are attempting to describe and systematize the meaningful differences in quality which arise in the manipulation of the interpretive vehicles of musical expression. The adjectives used in the description of musical timbre are of too general a nature to be really meaningful. Each type of voice and instrument has built up its own vocabulary without regard to its meaning to the musician in general. It is fair to state also that with voice as well as

instrument there seems no agreement on what is desirable in tone quality. So it is not merely a matter of change of epoch with its attendant desirable musical timbre. The musical psychologist has thus a fine opportunity to catalogue these differentiable qualities, to note the musician's response to them and to remove some of the element of fad and fancy in the field of tone quality. The composer, too, will do well to take advantage of the tremendous possibilities of the new musical instruments and to further stimulate the inventor as well as the performer in his art.

The constant interplay of the influences of the demands of the composer for the technical improvement of musical instruments, and vice versa, the stimulus of the artisan's development of musical vehicles of expression on the composer's creative urge had to be slighted in the foregoing, for the subject is worthy of far greater consideration than casual mention would have given it. This is true also of the tremendous progress made in the interesting study of psychological effects used in "putting over the footlights" the performer's message to the audience. How keenly this need is felt by the artist is indicated by Paul Robeson's endeavor to feel equally at ease in all the auditoria he encounters while on tour. He accomplishes what he desires, regardless of the hall, by the use of what he terms an "acoustical envelope," from which he is able to project his voice with a degree of satisfaction quite as great as that which he might derive from "singing in the privacy of his own bathroom" (to quote Sir James Jeans). And lastly might be mentioned the regretable omission of any attempted prognosis of the music of the future, except by innuendo. A resumé of the trend of the times indicates a pendular swinging from the rational music—as in the era of polyphony to the more sentimental type of the Romantic School, and back, again and again. The trace of this great cyclical sweep seems to indicate that the world of music should now be entering an epoch of a logical approach to the meaning of musical sounds, but such a trace is painted with an extremely coarse brush, and would probably cover up many of the nauseating details momentarily exposed to view. Yet, much that is truly worthy is also coming to light. These are all interesting chapters in themselves and it is to be hoped that the demands

factors in terms of average rates and extents or other characteristics does not offer a true analysis of conditions necessary for artistic effects. An instrument, therefore, which offers any of these factors in terms of such averages definitely tends to limit freedom of expression. Seashore's coworkers give fine evidence in their phono-photograms of the wide range in variation of such elements of expression, but choose to interpret their results in terms of the average rates and extents of the vibrato rather than to carry out a detailed analysis to obtain the meaning of the rate of change of these variants. This quality is known to be not merely dependent on the relative intensities of the overtones of the complex note. The ear offers tones not intended by the composer, even when only a pure note is wanted, if the intensity is sufficiently raised. This is complicated by tones in combination. Phase relationships and their effects have already been mentioned. Control of fine increments of frequency change associated with what is known as tendency tones offers a further heightening of interpretive effects. This is commonly known among musicians as psychological intonation.

Manufacturers of modern electronic instruments have by no means attempted to exhaust the known possibilities at their command. Any number of patents will probably never be commercially utilized. A sufficient approximation to satisfy the buying public is obviously the temporary order of the day, but competition and the ever-increasing appreciation of artistic values will tend to further stimulate inventive genius. The new instruments, with the manufacturer's choice of tonal qualities and resultant psychological effects upon the buyer, beautifully reflect the trend of current opinion as to what is today acceptable in tone quality, for it is deemed wise to give the public what it thinks it wants.

Serious psychologists are attempting to describe and systematize the meaningful differences in quality which arise in the manipulation of the interpretive vehicles of musical expression. The adjectives used in the description of musical timbre are of too general a nature to be really meaningful. Each type of voice and instrument has built up its own vocabulary without regard to its meaning to the musician in general. It is fair to state also that with voice as well as

instrument there seems no agreement on what is desirable in tone quality. So it is not merely a matter of change of epoch with its attendant desirable musical timbre. The musical psychologist has thus a fine opportunity to catalogue these differentiable qualities, to note the musician's response to them and to remove some of the element of fad and fancy in the field of tone quality. The composer, too, will do well to take advantage of the tremendous possibilities of the new musical instruments and to further stimulate the inventor as well as the performer in his art.

The constant interplay of the influences of the demands of the composer for the technical improvement of musical instruments, and vice versa, the stimulus of the artisan's development of musical vehicles of expression on the composer's creative urge had to be slighted in the foregoing, for the subject is worthy of far greater consideration than casual mention would have given it. This is true also of the tremendous progress made in the interesting study of psychological effects used in "putting over the footlights" the performer's message to the audience. How keenly this need is felt by the artist is indicated by Paul Robeson's endeavor to feel equally at ease in all the auditoria he encounters while on tour. He accomplishes what he desires, regardless of the hall, by the use of what he terms an "acoustical envelope," from which he is able to project his voice with a degree of satisfaction quite as great as that which he might derive from "singing in the privacy of his own bathroom" (to quote Sir James Jeans). And lastly might be mentioned the regretable omission of any attempted prognosis of the music of the future, except by innuendo. A resumé of the trend of the times indicates a pendular swinging from the rational music—as in the era of polyphony to the more sentimental type of the Romantic School, and back, again and again. The trace of this great cyclical sweep seems to indicate that the world of music should now be entering an epoch of a logical approach to the meaning of musical sounds, but such a trace is painted with an extremely coarse brush, and would probably cover up many of the nauseating details momentarily exposed to view. Yet, much that is truly worthy is also coming to light. These are all interesting chapters in themselves and it is to be hoped that the demands

for such information may be satisfied by further discussion. All that could be hoped for in this paper was the stimulation of a desire for a better understanding of the stuff out of which music is made and its effect upon the eager listener. Too long have we, as musicians, rolled our eyes toward heaven, implying that our inspired moments came from that general direction. It was a good trick as long as we were able to "get away with it," for by explaining but little, we were able to tacitly admit that we *were* inspired and were thus saved the necessity of having to prove it. We are living in a different age now and it seems to be becoming increasingly difficult to justify one's creative urge or interpretative attitude with *wishful* thinking.

THE STORY OF THE BICYCLE.

BY

N. W. SAMPLE, JR., AND T. COULSON,

Members of Staff of The Franklin Institute.

The romance of the bicycle usually opens with the construction of the "Draisine" in the year 1813. But let us take a glance into the gardens of the Palais Royal in Paris, toward the end of a warm afternoon in 1791. Only two years earlier the Bastille had fallen, but it was already fashionable to be seen promenading in the Gardens among the elegant young men and the rising politicians. On this particular afternoon the promenaders under the chestnut trees were startled by the sight of a young man, well known for his eccentricities, propelling a strange animal along a pathway. The young man, it was the Chevalier de Sivrac, apparently held the head of a lion between his hands while he sat astride two wheels. His progress was accomplished by a vigorous propelling of his long legs on either side. So long as he kept going straight ahead the Chevalier contrived to make good progress, but when he reached the end of the alleyway he was forced to pause, slew his vehicle around, and start off again in the desired direction.

It was a delightfully novel way of passing the time, and it provided amusement for the bystanders.

But was the Chevalier de Sivrac the inventor of the velocipede? It is more than doubtful.

Literary pilgrams to the church of Saint Giles in Stoke Pogis, famous for its association with Grey's *Elegy written in a Country Churchyard*, must occasionally be startled when they learn the age of the "Bicycle window" in that church. This window contains two figures, either of which would make it unique as a piece of ecclesiastical decoration. One figure is that of a cavalier smoking a long clay pipe. The other, more appropriate to our purpose, is that of a celestial trumpeter trundling a velocipede over a cloud-bank. As the

cloud furnishes a somewhat restricted area for this precarious sport, the velocipede is thoughtfully attached by a rope to—the Sun!

Since this window dates from 1642 it is by far the earliest suggestion of the velocipede which the Chevalier de Sivrac introduced into Paris in 1791. This vehicle, later called a "Célérifère" or "Vélocifère," had an instantaneous success. Not only was it eagerly embraced by the children, but the machine gained a great popularity among the young dandies of the period, hence its common name of "dandy-horse." The wheels were then 27.5 inches in diameter. The newspaper *Le Siecle* reported in 1802:

> The *vélocifère* is an instrument made of wood in the shape of a horse or other animal and is fitted upon two wheels of equal dimensions. It was at the commencement of our century that the exercise was the fashion and was practiced by the *fine fleur* young gentlemen of Paris. The Pavillon de Hanouvre was the rendezvous of the ardent lovers of the pastine. Outside the well known cafe situated on the Boulevard des Italiens a number of matches were arranged to be run towards the Rue Royale. . . . However, the most important races took place along the Cours-la-Reine and big cash prizes were offered. . . . Betting was lively.

On May 19th, 1804, a musical comedy called *Les Vélocifères* was opened at the Vaudeville in Paris.

About the year 1816, another Frenchman, Joseph Nicephore Niepce (also known as a pioneer in photography), improved de Sivrac's machine by enlarging the wheels. He baptized his machine the "Célérifère" but did not have originality enough to depart from the horse's head in front.

However, the scene had changed, momentarily at least, from Paris to Carlsruhe, in Germany, and Baron von Drais comes on the stage. He was the state forester in the Duchy of Baden, and had become weary of tramping long distances through the forests. In order to spare himself from fatigue Carl von Drais built himself a velocipede. The example of "Draisine," as the machines were now called, in The Franklin Institute has a solid iron frame (although the original was constructed entirely of wood). The front wheel is mounted in a fork, sprocketed in the front end of the backbone. Leaning his elbows on a well padded support, the rider

scuffed his way along the road, using right and left foot alternately, at the same time maintaining his balance and steering with the handle-bar affixed to the fork. On February 17th, 1818, Baron von Drais acquired a French patent for an improvement on his earlier machine, the same year in which Denis Johnson, a London coachbuilder, also received a patent for a similar machine.

The French were not enthusiastic in their reception. *Le Petite Chronique de Paris* wrote on April 7th, 1818:

> The velocipede of Monsieur le Baron de Drais was given a trial yesterday morning in the gardens of the Luxembourg and the experiment of 1818 showed no improvement upon the Célérifère of 1790. . . . The machine can never be of any utility as it can only be used in a garden or park on a well kept walk or road. . . . If the numerous spectators were not satisfied with the result the curious were well repaid by the presence of a number of pretty women in their most brilliant dresses. A nut being lost it was no longer possible to use the machine.

The English were decidedly more optimistic, as a writer in the *Liverpool Mercury* (April 24th, 1818) declared that "the machine went quicker than a man running at speed and the riders did not appear fatigued. . . . The Draisiennes (*sic*) appear to be convenient for the country and for short journeys on good roads."

In spite of the lofty tone adopted by *Le Petite Chronique* in its initial notice, it returned to the subject a few months later, bristling with indignation at the growing popularity of the accursed machine, which it now regarded as "the plot against our horses." It reluctantly admits that the speed attained by the riders equalled that of a trotting horse. When the machine was introduced into the United States in 1819 it created a sensation. An improved type was manufactured by David and Rogers in Troy. A riding establishment was opened in the Bowling Green in New York; riders proudly dashed up and down the Bowery; or sped gaily down the grade from Chatham Street to the City Hall Park.

In 1819 W. K. Clarkson of New York was granted the earliest American patent for an improved velocipede. The craze spread with the violence of an epidemic of measles. *Ackermann's Magazine* joyfully proclaimed in the first year of

trial: "The swiftness with which a person well practised can travel is almost beyond belief; 8, 9, and even 10 miles an hour, it is asserted, may be passed over within an hour on good level ground."

To Baron Carl von Drais, then, belongs the credit for having developed the first practical velocipede, since his was the first to have a front steering wheel, although there is a lingering doubt about Niepce's priority. What is certain is, that Drais furnished the impulse which propelled the vehicle into universal popularity.

Although many eminent men, like Michael Faraday, fell victim to the lure of travelling at the incredible speed of 8 miles an hour, none of them appears to have thought of providing any means of mechanical propulsion until an enterprising Scottish blacksmith took the matter in hand. Kirkpatrick Macmillan, of Courthill, Dumfrieshire, Scotland, was the first man to realize that two wheels in line could be balanced and propelled by mechanical action. Since he accomplished this in the year 1839 we have passed the centenary year of the bicycle.[1]

Macmillan's machine had wooden wheels with iron tires. The frame consisted of a wooden bar extending in a curve from the top of the front wheel to the hub of the rear (driving) wheel. This bar was forked to receive the rear wheel, and was provided with axle bearings. The front wheel revolved in an iron fork connected with the handle-bar by a pivot passing through the frame. Cranks were keyed to the ends of the rear axle. They were driven by connecting rods from intermediate connecting points in two swinging levers pivoted near the steering wheel and carrying wooden treadles at their lower ends. Both axles run in brass bearings. The front wheel was 32 inches and the rear wheel 42.5 inches in diameter; wheel base 48 inches; weight 57 lbs.[2]

[1] An early Draisine type fitted with pedals is on exhibition in Munich, but it is admitted that the pedals were added to the machine in the year 1862.

[2] The machine which usually appears in histories of the bicycle as "an original" Macmillan machine is reproduced from the example in the Science Museum, London. This machine is fitted with a brake, which has led several writers to attribute the brake to Macmillan. The Museum catalogue clearly says that this machine was probably made by Thomas McCall about 1860 and that the brake was added after Macmillan's day.

Both Macmillan's old smithy in Courthill and his tombstone in the Old Kirk Cemetery bear suitable inscriptions recognizing him as the inventor of the earliest mechanically propelled bicycle, but neither bears testimony to another claim to doubtful distinction which belongs to him. The *Glasgow Herald*, June 10th, 1842, reports that Macmillan "on entering Glasgow at the finish of a 40 mile ride, knocked over a child owing to the crowd of people to see his novel iron horse. He was fined five shillings at the Gorbals police court." Macmillan, therefore, became the first bicyclist to be penalized for traffic violations!

Although Macmillan became a familiar figure on the road between Dumfries and Glasgow, and he was exceedingly liberal in permitting others to copy the design of his bicycle (Thomas McCall made several which he sold for $35), the overwhelming majority of "bicyclists" remained faithful to their earlier velocipedes. A full quarter century was to pass before the familiar pedals were to be fitted to a machine.

The actual credit for priority of invention is still in dispute. One claimant, Ernest Michaux, has several witnesses; the other, Pierre Lallement, has been unable to furnish any corroborative evidence to his affirmation. The story of Ernest Michaux, later a coachbuilder in Citè Godot de Mauroy, Paris, is probably best told in the words of his younger brother who furnished the following account to the editor of *Le Velo* (March 28th, 1898):

> In the month of March 1861, a hatmaker, Monsieur Brunel, of the Rue de Verneuil, Paris, brought his vélocifere to my father for the front wheel to be repaired. The same evening my brother Ernest, 19 years old, took the machine out for a trial on the Avenue Montaigne. "I can balance myself alright, but it is as tiring to hold up my legs as to give the impulsion on the ground with my feet," he said to my father in my presence on returning home. "Well then," said my father, "fix a small support on each side of the front fork . . . or, better still, to rest your feet adopt a cranked axle in the hub of the front wheel, and then you can make the wheel revolve as if you were turning the handle of a grindstone!"

Thus a grindstone furnished the inspiration and Pierre Michaux the idea for Ernest Michaux to construct the first pedal bicycle suitable for production upon a commercial scale.

At the Universal Exhibition of 1867 the new machine occupied a prominent position. Michaux was probably also the first man to fit a brake to a bicycle. It worked upon the principle of a shoe acting upon the rear wheel, which was applied by tightening a cord that could be wound around a movable handle-bar grip. This is the same type of brake which appears on the "Macmillan" machine (of about 1860) in the Science Museum, London, but not claimed as original. This same brake is on the Lallement "boneshaker" (1863) in the Franklin Institute collection. The Michaux machine was much lighter and more practical than anything that had yet been offered to the public. Its inventor continued to add improvements. Iron tires were abandoned in favor of solid rubber, and the saddle was mounted on springs. These refinements added greatly to the popularity of the machine, for Michaux's account books show that in 1861 he made two machines; in 1862 the number had jumped to 141; and in 1865 it had passed the 400 mark.[3]

The claims of Pierre Lallement do not appear to rest upon equally substantial grounds. The evidence shows that he was born in Pont à Mousson and did not go to Paris until 1863, two years after Michaux had applied pedals to the vélocifère. However, he did find employment with the elder Michaux in his coach works, but stayed there only a short time before departing for the United States. Pratt states[4] that he was so poor that he had to work his passage as a stoker. In any event, he arrived in Ansonia, Conn. and set about looking for a job. While searching for employment Lallement was seen peddling about New Haven on a very crude "boneshaker" of his own design and construction. The unusual sight appealed to the imagination of a native called Carroll.

The velocipede had not entirely vanished from the American scene, and when Carroll saw the Frenchman gayly scuttling about the square of New Haven on a machine made from one wheel of a boy's velocipede and a larger wheel of unknown origin, his canny Yankee intelligence told him that

[3] De Saunier, B. Histoire de la Locomotion Terrestre. Paris, 1936.
[4] Pratt, C. E. American Bicycler. 1879.

a miracle had happened. On May 4th, 1866, P. Lallement and J. Carroll filed application for the first American patent for a mechanically propelled bicycle. Apparently, Carroll was not able to furnish the funds to exploit manufacture, but the craze for bicycling had gripped France and England. America could not long remain immune, so the Lallement patent was acquired by Calvin Witty, of New York, and production was begun.[5]

Meanwhile, Lallement had returned to Paris in time to see his former employer's bicycles displayed at the Universal Exhibition in 1867. He missed the first boom years in America, and had no sooner started making bicycles in Paris than the Franco-Prussian War broke out. For the time being, with more serious thoughts to occupy them, the French went into eclipse as cycle manufacturers. Lallement, however, bobbed up again in 1896 in the factory of the well known American bicycle firm of the Pope Manufacturing Company.

It is to be observed that Lallement had not improved upon the Draisine in his method of starting. The rider still set off running with his feet on the ground and only put his feet to the pedals when he had gained some impetus. The Lallement model in The Franklin Institute collection has cranks with two holes in them so that the length may be varied from 7.5 to 6.5 inches. The pedals are wooden spools. The front bearings are tightened up by cotters. The brake on the rear wheel is the conventional type of the period, a shoe operated by tightening a cord by rotating the hand grip. The saddle is mounted on a long plate spring attached to the head at the front and to two struts from the back wheel bearing. The wooden wheels have iron tires and are 36 inches, front, and 30 inches, rear.

Before leaving Paris to the Prussians some attention must be given to the exhibits of the "Bicycle Show" held at the Prè Catalan from Nov. 1st to 5th, 1869. Some of the anticipations of later developments as seen by the staff of *La Vélocipéde Illustrè*, are truly amazing. Anthoni showed a bicycle with a four-speed gear. Aristide Berges of Lancy, had a well made machine which produced two revolutions of

[5] Duncan, H. O. The World on Wheels. Privately printed.

the wheels for one of the pedals, to be utilized only on level ground, and the gear reduced to one revolution when ascending hills. Berroyer, of Grenoble, introduced mud-guards and foot-rests. Boeuf, of Tarare, exhibited a machine "with independent pedals—that is to say, they can remain stationary while the machine continues its impulsion"—free-wheeling! E. Meyer showed bicycles with wire spokes, held in position at the hubs by brass nuts. These spokes were invented by Joshu Heilmann in 1861.

An important contribution toward improvement in the bearings was the adoption of ball bearings in 1869 by Suriray in France and by Strassen in England. The great popularity achieved by the new bicycles after the freer running ball bearings were introduced gave the latter a widespread reputation and ensured their adoption in innumerable mechanical applications.

A young man called Rowley B. Turner had introduced the Michaux bicycle into England, and he persuaded his uncle (manager of the European Sewing Machine Company) to undertake its manufacture in that country. Turner then applied himself to further improvements. He produced the "ordinary," that creation with a 60-inch front wheel and a 20-inch rear wheel, which is a familiar feature of old prints, and whose appearance in street parades never fails to stir the hilarity of our disrespectful generation. As a matter of fact, this is the first true bicycle; the forerunners being more accurately described as velocipedes.

The introduction of the solid rubber tire had done much to reduce vibration and jolts. They had diminished the leg power required to propel the machine. As a direct consequence the larger wheel could be driven with the same ease as the smaller one. The motive power was applied directly to the tall driving wheel; wheel, cranks, and pedal-pins forming one rigid body. The mass center of the rider was almost immediately above the center of the wheel, so that any sudden obstruction to the free motion of the wheel had the effect of hurling the rider over the handle-bar. Moreover, the difficulty of mounting the "perch," as the saddle was called, required so much skill that, when racing, the contestants were forced to break speed, halt, dismount, and leap

into the saddle again. Agility in mounting was regarded as an equivalent to speed in motion.

The "ordinary" became immensely popular. One of its exuberant admirers declared that "it runs, it leaps, it rears and writhes, and shies and kicks; it is beneath its rider like a thing of life, without the uncertainty and resistence of an uncontrolled will." Except for the last sentence we may accept the description as accurate. Admitting that the high wheel had its disadvantages in mud and snow, this same enthusiast (he was Charles E. Pratt, author of the *American Bicycler*) claims that 100 miles a day was a fair day's ride, 50 miles was mere pastime, and 20 miles no more than a pleasant diversion before breakfast. Sandy, stony, and cobbled roads were to be avoided upon his recommendation. But the sport of bicycling was "manly, innocent, humane, and rational."

In spite of the fact that the invention of the "safety" bicycle followed hard on the heels of the "ordinary," the latter continued to grow in popularity. H. J. Lawson, of Brighton, England, made the first safety out of the wheels of his perambulator! His first patent on the design was granted in 1876, but it was not until 1885, when the rider of a safety beat the field in a 100 miles race, that its superiority over the ordinary was established.

In spite of all the advantages that the ordinary conferred upon its blissful owner, the British were not satisfied with it. They set to work almost immediately to tinker with the design. The first important step was the "Facile," which shifted the mass center of the rider further behind the center of the driving wheel. This was performed by driving the crank by means of a short coupling rod from a point about the middle of the driving lever, the end of which formed the pedal. The fork of the front wheel was continued downwards and forward to provide a fulcrum for the lever. The movement of the pedals was one of up and down oscillation, and quite different from the circular action of the "ordinary" pedals. One of these "Facile" machines was ridden by an enthusiast 242½ miles in 24 hours. In addition to the increased speed the design provided a slightly enlarged margin of safety when obstructions were encountered.

The first rear-chain-drive safety bicycle was built by Lawson, who rode it about the streets during the years 1874 or 1875—the inventor was a little hazy about the date. He patented it in 1876. In this machine a short forked bar projected downwards from the middle of the main bar and supported the crank axle which turned in plain bearings. The chain was of the "lawn-mower" type. But it remained for the "Rover" to embody most of the principal features of the modern bicycle. The diamond shaped frame and conventional sized wheels became standard. Ball bearings were definitely incorporated in 1885. Meanwhile James Starley had patented the tangent-spoked wheel, and the differential gear in combination with the chain drive and rotary motion for tricycles. Clement (of Paris) speedily grasped the idea of the differential axle and applied it to the automobile, marking the introduction of the invaluable "live axle." Starley released a perfect torrent of innovations. In the year 1884 no less than 200 distinct patterns of bicycle were placed on the market. The craze for novelty and improvement progressed with cumulative effect until, in 1896, more than 7,000 bicycle patents were issued in England alone.

The machines had gradually become lighter, due to the conception of hollow forks and rims. We have seen how the grindstone inspired Michaux; now a sword scabbard suggested the idea of hollow construction to Jules Truffault of Tours, France.

There remains but one important development to record—that of the pneumatic tire. As it completely revolutionized cycling and ensured universal popularity for the pastime it is somewhat ungenerous to leave it to the position of an afterthought. It is generally assumed that the "air" tire originated with John Boyd Dunlop, but investigation reveals that as early as 1845 a provisional patent was granted to R. W. Thomson, of London, for "elastic bearings around the tires of the wheels of carriages for the purpose of lessening the power required to draw carriages, rendering their motion easier, and diminishing the noise they make when in motion." In effect this was the earliest pneumatic tire. It was made of rubber and leather, with a thin metallic tread. They

were secured to the wheels by large headed screws or bolts passing through the felloe.

However, these "elastic bearings" did not catch the public fancy. They remained unknown outside of Thomson's own circle of acquaintances, and were no more than a blurred memory when the bicycle was attaining the first blush of its popularity.

Not until 1888, when John Boyd Dunlop, a veterinarian of Belfast, Ireland, working in a disused bedroom of his home, made the first true pneumatic tires from sheet rubber. The replica of this original tire in The Franklin Institute collection shows that, whatever modifications and refinements may have been made, the pneumatic tire is still substantially as Dunlop made it for the greater convenience of his young son.

In following the chronological development of the bicycle's main features we have strayed away from its progress in the United States. Early in 1877 an English manufacturer visiting Boston wished to indulge in his favorite pastime of cycling. Somewhat dismayed to find the primitive vehicles available for his transportation, he had a bicycle made locally upon his own specification, and rode it about the city of Boston. Among the local men who were favorably impressed by the possibilities when the machine was in the hands of an expert, was Colonel Albert A. Pope. Unable to restrain his curiosity and his interest, he visited London and Coventry (where the British bicycle makers had established themselves) in order to make a survey of the manufacturing conditions, tools, etc. requisite for a plant. On his return to this country Colonel Pope opened a warehouse for bicycles and a riding school for instruction at 87 Summer Street, Boston, where imported bicycles could be bought and their control mastered. Soon afterwards the Pope Manufacturing Company, of which he was the president, began to make the "Columbia" bicycle, a high wheeler. The American cycle industry was born.

A year or two ago some of the more popular "stars" of the motion picture screen revived the passion for cycling, so that it has resumed much of its fever-grip upon the youth of the country. In 1938 more than a million cycles were manufactured and sold in this country. The gap between Pope's modest beginnings and the recent revival can best be

told by someone whose memory covers the flourishing period of clubs, meets, and races. Laws and courtesies of the road were drawn up, not even omitting the etiquette to be observed when passing or overtaking horses. Manuals for riders were written, although the earliest [6] had appeared in 1869. Before the automobile appeared upon the roads in any number, cycling was the most popular form of transportation, exercise, and amusement. Strenuous efforts were made to abolish mud upon the roads and to level out the ruts. There are many men living today, who take their pleasure behind the wheel of a motor car and who are willing to relinquish their grip long enough to wax enthusiastic over the innocent joys of cycling. Their tales are worth listening to by a generation that has been weaned on a gas pump.

The collection of old bicycles in The Franklin Institute Museum contains illustrations of all the principal steps in the development of the machine, and also contains interesting examples of multi-seated machines used for pacing famous racers, that are rarely to be found.

---

[6] Goddard, G. T. The Velocipede. New York: Hurd and Houghton. 1869. The first periodical, *The Velocipede*, edited by W. Chester King also appeared in the same year.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

DANGEROUS ANTI-FREEZING SOLUTIONS.

The danger of using anti-freezing solutions containing calcium chloride and other salts in automobile cooling systems has long been recognized by the Bureau's automotive engineers who have made a special study of this matter. They point out that the use of these solutions is prohibited in all Government-owned motor vehicles. An important step was taken recently by the War Production Board in its order forbidding the manufacture of anti-freezes compound with inorganic salts or petroleum distillates.

The present critical situation, which if not controlled might result in the actual destruction of thousands of automobiles, is an outgrowth of the shortage of ingredients used in the conventional anti-freezing solutions. Many substitutes are being marketed, some of which, containing calcium chlorides and other salts, are advertised under brand names as permanent anti-freezes.

Attempts to use these brine solutions have been made ever since automobiles were first driven in freezing weather, and serious results have always followed. The most expensive of these troubles has been hidden corrosion in the cooling systems. Water pumps and cylinder heads, particularly when the latter are of aluminum alloys, have developed leaks which show up only after much damage already has been done. Under present conditions parts thus damaged, particularly radiators made of copper, very probably cannot be replaced.

Marketers of calcium chloride anti-freeze compounds sometimes use inhibitors which they claim guard against corrosion. While it is always possible that some such inhibitor may be found, the Bureau does not know of any that is effective under the conditions of actual use, even though some of them ap-

* Communicated by the Director.

parently are effective when tested in the laboratory at ordinary room temperatures.

Under present conditions, with no new cars to be had and with many replacement parts off the market, it approaches criminal negligence to take chances on the use of any of the anti-freezing solutions containing inorganic salts such as calcium chloride; certainly until some disinterested agency has shown beyond a doubt that this can be done with safety.

Any radiator preparation of undisclosed composition should be analyzed or avoided. If such a solution weighs between 10.5 and 11.5 pounds per gallon, it probably is based on calcium chloride. If the motorist already has a solution of unknown composition in his radiator, the following test is suggested:

Put a few spoonfuls of the radiator solution in an iron skillet or dish (do not use aluminum) and heat on the stove, letting the solution boil down slowly. If there is a substantial deposit of salt left, the solution was a brine solution.

A simple chemical test which any layman can apply is this:

Put a small quantity of the radiator solution in a water glass and add silver nitrate solution with a medicine dropper. The formation of a white deposit or precipitate (silver chloride) will indicate that the anti-freeze was a brine solution. Empty the glass and rinse with household ammonia before using it for any other purpose.

PROPOSED SUBSTITUTES FOR RUBBER.

Since the beginning of the rubber shortage many samples of proposed substitutes for rubber have been submitted to the Bureau for test. Although many different materials have been proposed, a great majority of them fail to meet certain simple tests which have been applied. It seems worthwhile, therefore, to describe tests to determine whether or not a proposed material possesses the basic characteristics of rubber to a sufficient degree to warrant further consideration and laboratory study.

Characteristic Properties of Rubber.—If a material is to serve as a practical substitute for rubber, it should be extensible, resilient, tough, waterproof, resistant to drying,

and relatively unaffected by summer heat and winter cold. Simple tests, which anyone can apply, to determine these properties are as follows:

1. Cut a strip of the material and note how much it can be stretched before it breaks. Observe also whether the broken portions snap back or whether they recover only slowly. If a material will snap back after being stretched to three or four times its original length, it has promise as a substitute for rubber; if it breaks before being stretched this much or if it recovers slowly, its probable usefulness will be correspondingly limited. If it cannot be stretched to at least double its original length, it can scarcely be considered for use in the place of rubber.

2. Try to cut the material with the thumbnail. If it resists cutting, it merits further consideration, but if it can be picked to pieces or if it crumbles when rolled vigorously between the thumb and forefinger, it could be considered only for minor uses, such as erasers.

3. Soak a thin piece of the material in water for a few days and note whether it disintegrates, swells, or becomes weaker than the original material. Although inability to withstand water need not bar a material from further consideration, it should be borne in mind that in most applications of rubber, waterproofness is an important consideration.

4. Keep a thin piece of the material in a warm, dry place for a week and note whether it retains its original extensibility and resilience. If it dries out or becomes hard and brittle, it can be of no use as a substitute for rubber.

5. Put some of the material in the freezing compartment of an electric refrigerator for a few hours and note whether it retains its extensibility or whether it becomes hard and brittle. Also put some of the material into boiling water and look for evidences of softening and melting. A material which does not withstand these extremes of temperature could replace rubber in a few applications, but would not be generally useful.

Factice and Gels.—A majority of the proposed substitutes submitted to the Bureau represent two types of products which, though well known to industry, apparently have been independently rediscovered by many inventors. These prod-

ucts are *factice*, prepared by the vulcanization of oils; and *gels*, made from glue or gelatine. A brief description of these materials will serve to indicate the respects in which they fail to meet the requirements outlined in the foregoing paragraphs as a general substitute for rubber.

The public seems to be almost entirely unfamiliar with factice, although it is an important industrial material and was known before rubber was introduced into Europe. The rubber-like properties of factice are such that it is often called "rubber substitute" by the trade. Commercial factice is of two main types. A brown or dark factice is prepared by heating vegetable or fish oils with sulfur. The vegetable oils may include rapeseed, linseed, corn, cottonseed, poppy seed, and caster oils. A white or light factice is prepared by the cold vulcanization of an oil with sulfur monochloride; rapeseed or corn oil is favored for the purpose. The principal application of factice is as a compounding ingredient, for which purpose it has been used for nearly 100 years. It is compatible with synthetic as well as with natural rubber and is employed in combination with them in making insulated wire, druggists' sundries, erasers, stationers' goods, and various other products. The use of factice alone is limited to minor products, such as "Art Gum" erasers, because, in spite of many efforts, it has never been developed with properties which can meet the tests of extensibility and resilience, toughness, and resistance to temperature change shown to be necessary for a general rubber substitute.

Many persons are unaware of the fact that rubber-like compounds made from glue and gelatine have long been known and used in industry. They were extensively employed at one time in making printers' rolls, but were displaced to a large extent by synthetic rubber in the 1930's. With the present rubber shortage, however, they are coming back into use. The compounds from which printers' rolls are made usually contain glue or gelatine, water, glycerine, and a tanning agent. The glycerine keeps the compound from drying out, while the tanning agent stabilizes the compound and keeps it from softening with heat. At best, the gels made from glue and gelatine are so inferior to rubber in extensibility, toughness, and resistance to water that it is doubtful whether they

will satisfactorily replace rubber in any but a few special products.

CONSERVATION OF LINSEED OIL IN PAINT.

The conservation of linseed oil in paint is the subject of a Letter Circular (LC717) by E. F. Hickson, chief of the Bureau's section on paints, varnishes, and bituminous materials. This is intended as a contribution to the War effort, and the recommendations have the approval of the War Production Board, the Lead Industries Association, and the National Paint, Varnish and Lacquer Association. The principal methods of conserving linseed oil are discussed, with particular emphasis on less raw oil and more thinner when used with white lead paste, etc., for exterior wood and with red lead, etc., for exterior metal. Tables of customary and proposed mixing formulas are given. The new system of two-coat exterior painting is described, as well as systems of interior painting, and the use of cold-water paints for interior and exterior use. Lists of Bureau Letter Circulars and of Federal Specifications for paints are included.

Copies of LC717 are obtainable without charge from the National Bureau of Standards, Washington, D. C.

MOISTUREPROOF MATCHES.

Soldiers and sailors stationed in the tropics carry their strike-anywhere matches in small cannisters. When these are opened in the damp jungles or at sea, the matches absorb moisture and finally become worthless. To overcome this difficulty, the Bureau has experimented with matches that have been coated with moisture-resistant materials. Some of these were kept at a temperature of 100° F. in an atmosphere of 95 per cent. relative humidity until none ignited when struck. Others were completely immersed in water and tested at intervals. One coating gave very promising results, in that matches treated with it were still usable after 5 days' exposure at 95 per cent. relative humidity or immersion in water for four hours. An order has been given to a manufacturer for an experimental lot of these matches.

IMPACT RESISTANCE OF CONCRETE SHIPS.

The current restrictions on the use of steel plate have again turned attention to the possibilities of constructing seagoing cargo ships and barges of reinforced concrete. One of the items of concern in the design and construction of concrete ships is the resistance of the hull to impact loads concentrated over a small area, such as might be encountered in minor collisions with floating debris, pier fenders, etc. The use of supplementary reinforcement in the form of a series of coils of large diameter wire, commonly known as spirals, has been suggested to increase the resistance of the reinforced concrete to impact loads. Therefore, a number of tests were conducted by Ralph W. Kluge on reinforced concrete slabs of the design contemplated for use in the hulls of ships, and of several thicknesses, to determine the effect of supplementary spiral reinforcement on the impact resistance of the slabs. Results of the tests confirmed the value of the spiral reinforcement, showing that the slabs containing the spirals had a resistance to impact of from $1\frac{1}{2}$ to almost 3 times that of similarly designed slabs without spirals. Also, the arrangement of the bar reinforcement in the slabs apparently influenced their resistance to impact.

BLANKET AND SHEET COMBINATION FOR OUTDOOR USE.

In an open lifeboat a combination of a blanket and sheet affords more protection against wind and rain or snow than a blanket alone. The combination of a blanket and a water and wind resistant cloth also has a number of advantages for army service, where blankets must meet all sorts of conditions. Although blankets and sheets are customarily used in homes, hospitals, and barracks, the possibilities of a sheet-blanket combination for outdoor use, where protection from wind and rain or snow as well as from cold is important, apparently has not received very serious consideration.

A study of the properties of blankets, recently completed by Herbert F. Schiefer of the Bureau's textile section, included tests of combinations of blankets and sheets. The blankets selected for these tests varied greatly in air permeability, but in comparison, the permeability of the sheets was

always low. The effect of moving air on the heat-retaining properties of the blankets and of the blanket between two sheets was evaluated. The results of this study will appear in RP1529 in the March *Journal of Research*. The effect of laundering on the weight, thickness, compressibility, compressional resilience, breaking strength, air permeability, and thermal transmission of the blankets is also reported.

Tank Built With Horizontal Staves.—(*Engineering News-Record*, Vol. 129, No. 19.) Wood staves placed horizontally instead of in the usual vertical position, eliminated the need for steel bands around a tank 60 ft. in diameter and 9 ft. high recently built at Tacoma, Wash. The design was worked out in search of an oil storage structure that would require a minimum amount of steel. Not only does the new design provide storage capacity that can substitute for all-metal tanks in the 200,000 gal. size, but it fulfills this need with only one-third the steel required in standard wood tank construction using vertical staves and circumferential steel bands. The new tank has a concrete base which carries anchors for the 4 × 6 in. vertical stiffeners spaced 10 ft. on centers around the circumference. After the concrete base was kept moist for a 14-day curing period, the inside vertical stiffeners were fastened in place with lagscrews and the horizontal staves forming the wall were bent around and clamped to the stiffeners. These staves are clear Douglas Fir, selected from stock at the mill and air dried to a moisture content of about 18 per cent. The staves were cut from 20 ft. lengths of 2 × 6 stock, surfaced to $1\frac{5}{8}$ in. thickness and provided with tongue-and-groove joints. Joints between the ends of staves were made with 1-in. scabs, $\frac{1}{2}$ in. bolts and $2\frac{1}{2}$ in. split-ring connectors, the number of rings varying with the depth and the consequent pressure. Splines were inserted between the staves to make the end joints watertight. As each band was carried to a complete circle, stiffener clamps were released and the band was wedged against the next lower round. When all the horizontal staves were in place, outside vertical stiffeners were put on and the staves were fastened down to a tight fit by wedges driven into place under plates secured between each pair of stiffeners. A mastic was poured into the inside of the bottom joint between the timber and concrete base and the outer edge of this joint was grouted with 1 to 1 sand-cement grout hammered into place. The design was developed by HARRY R. POWELL, structural engineer, for the Texas Oil Co.

R. H. O.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, MARCH 17, 1943.

The stated monthly meeting of The Franklin Institute was begun by the playing of the National Anthem, at 8:15 P.M.

Mr. Charles S. Redding, the President and presiding officer, then called the meeting to order and announced that the minutes of the last meeting had been published in full in the March number of the JOURNAL OF THE FRANKLIN INSTITUTE; and that, if no objection were offered, the minutes would stand approved as printed.

On motion the minutes were so approved.

The Secretary, Dr. Henry Butler Allen, was then called upon for his report. He stated that since the last meeting the following additions to membership had been made:

Honorary	2
Sustaining	1
Active	96
Associate	33
Student	33
Total	165

The Secretary then extended a cordial invitation to all members to attend Medal Day exercises which this year will be held on Wednesday, April 21. He called attention to a radical departure from our ordinary procedure this year, stating that the medals will be awarded in the evening instead of the afternoon. The change has been made to meet wartime conditions. The functions will begin with a reception at 5:30, followed by dinner and the presentation of awards.

The Secretary pointed out that we have a very interesting group of men to be honored this year and that their presence, and the reading of papers by the Franklin Medalists, will make the event an outstanding one.

There being no further business, Mr. Redding then introduced Dr. W. F. G. Swann, Director of the Bartol Research Foundation of The Franklin Institute, and well known to the audience. Because of existing war regulations it was not possible for Dr. Swann to give his customary yearly report on the work of the laboratories. He therefore chose as his subject "Cosmic Rays," presenting it in a highly entertaining and lucid manner. The talk was illustrated with slides.

The meeting was dismissed with an expression of appreciation to the lecturer.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays from two until ten o'clock P.M.

RECENT ADDITIONS.

AERONAUTICS.

WEEMS, P. V. H. Air Navigation. Third Edition. 1943.

ALMANACS.

Bulletin Almanac for 1943.

ARCHITECTURE AND BUILDING.

GOODMAN, WILLIAM. Air Conditioning Analysis. 1943.
MATTHIAS, A. J., JR. How to Design and Install Plumbing. 1942.
PLUM, SVEND. Plumbing Practice and Design. Volume 1, 1943.

BIOCHEMISTRY.

BOOHER, LELA E., EVA R. HORTZLER, AND ELIZABETH M. HEWSTON. Vitamin Values of Foods. 1942.

CHEMISTRY AND CHEMIC TECHNOLOGY.

ADAM, NEIL KENSINGTON. The Physics and Chemistry of Surfaces. Third Edition. 1941.
BENNETT, H. Substitutes. 1943.
BRAUDE, FELIX. Adhesives. 1943.
CLAYTON, WILLIAM. The Theory of Emulsions. Fourth Edition. 1943.
DEMENT, JACK, AND H. C. DAKE. Uranium and Atomic Power. 1941.
HILL, G. ALBERT, AND LOUISE KELLEY. Organic Chemistry. 1943.
MANSPERGER, DALE E., AND CARSON W. PEPPER. Plastics. Second Edition. 1942.
Plastics Catalog 1943. 1942.
PLUNGUIAN, MARK. Cellulose Chemistry. 1943.

ELECTRICITY AND ELECTRIC ENGINEERING.

BLY, MERWYN. A Guide to Cathode Ray Patterns. 1943.
MARCUS, ABRAHAM, AND WILLIAM MARCUS. Elements of Radio. 1943.
WARE, LAWRENCE A., AND HENRY R. REED. Communication Circuits. 1942.

ENGINEERING.

American Society for Testing Materials. Standards 1942, Parts 2–3. 1942.

GRAPHIC ARTS.

SHARP, H. OAKLEY. Photogrammetry. Third Edition. 1943.
WYBLE, EUGENE. Sell Your Photographs. 1942.

MANUFACTURES.

American Foundrymen's Association. Transactions 1942. Volume 50. 1943.
SMITH, PAUL I. Principles and Processes of Light Leather Manufacture. 1942.
Tappi Committee on Abstracts and Bibliography. Paper-making Abstracts. 1942.
Thomas' Register of American Manufacturers 1943.

MATHEMATICS.

JANSSON, MARTIN E. Handbook of Applied Mathematics. Second Edition, Revised and Enlarged. 1936.

MECHANICAL ENGINEERING.

BELYAVIN, PAUL. Combustion-Chamber Design for Oil-Engines. 1937.
MOLLOY, E., Editor. Modern Oil Engine Practice. 1943.
KEHL, GEORGE L. The Principles of Metallographic Laboratory Practice. Second Edition. 1943.

METEOROLOGY.

SPITZ, ARMAND N. A Start in Meteorology. 1942.

MILITARY ENGINEERING.

HESSEL, M. S., W. J. MURPHY, AND F. A. HESSEL. Strategic Materials in Hemisphere Defense. 1942.

PATENTS.

U. S. Patent Office. Index of Trade-Marks 1942. 1943.

PHYSICS.

POLLARD, ERNEST, AND WILLIAM L. DAVIDSON. Applied Nuclear Physics. 1942.
ST. JOHN, ANCEL, AND HERBERT R. ISENBURGER. Industrial Radiology. Second Edition. 1943.

SCIENTIFIC AND TECHNICAL PROGRESS.

BAITSELL, GEORGE A., Editor. Science in Progress. Third Series. 1942.
COCHRAN, THOMAS C., AND WILLIAM MILLER. The Age of Enterprise. 1942.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Experimental Burns. Changes in the Phosphorus Content and Moisture Content of Muscle.—J. O. ELY. A loss of fluid from the blood and its accumulation in the injured areas results from burns. It has been more or less generally assumed that, with the lost fluid, various salts are lost from the blood serum. If this be true for all salts, P should be increased in burn-injured tissue. So far as the author is aware, no studies have been made heretofore of phosphorus changes in muscle.

EXPERIMENTAL.

Albino rats were used for these experiments. They were maintained on the laboratory stock diet and were given access to water at all times. They were not fasted prior to the experiments.

The burns were inflicted under ether anesthesia on the outside of one rear leg, the hair first having been clipped closely. The burns were made by the application to the skin of a circular iron $1\frac{1}{8}$ inches in diameter at 400° C. In some of the experiments (Fig. 6) the time of burning was 8 seconds, but in the greater part of the experiments it was 5 seconds.

Samples of muscle were taken at time intervals from beneath the skin of the burned area and also from the corresponding area of the opposite hind leg. The following estimations were made:

1. Total phosphorus. The tissue was digested with sulfuric and nitric acids and the phosphorus in the digest determined by the colorimetric method of Gomori (*Journal of Laboratory and Clinical Medicine*, **27**: 955, 1942). This colorimetric method was used for the other fractions as well.

2. Acid soluble inorganic phosphorus. The tissue was placed, immediately after weighing, into 4 per cent. trichloracetic acid, then cut finely with scissors, and extraction allowed to continue for 15 minutes at room temperature. The extract was filtered through ashless filter paper, the tissue

washed once with another portion of trichloracetic acid and twice with distilled water. Phosphorus was determined on the combined extract and washings.

3. Acid soluble organic phosphorus. This was obtained in the following manner. An aliquot portion of the trichloracetic acid extract was digested with sulfuric and nitric acids and the total acid soluble phosphorus determined. The difference between the total acid soluble phosphorus and the acid soluble inorganic phosphorus is the acid soluble organic phosphorus.

4. Acid insoluble phosphorus. The trichloracetic acid extracted tissue was digested and the phosphorus determined as described under total phosphorus.

5. Moisture. This was obtained by weight difference after drying the tissue at 105–110° C. overnight.

The tissue dried for moisture determination was used for total phosphorus estimations. For the other phosphorus fractions, other samples of fresh tissue were used. In the calculations of the values on the dry weight basis for acid soluble inorganic, acid soluble organic and acid insoluble phosphorus, it was assumed that the per cent. moisture in these samples was the same as it was in the samples which were used for dry weight estimation. In this way some error may have been introduced, especially in case of the burn-injured muscle, because the moisture content of 4–6 samples from the same burned animal might vary somewhat, due to varying intensity of the burns and to varying depth of cutting.

The data, shown graphically, indicate that beginning 15 minutes after inflicting the burns and extending for the maximum experimental period used (14 days), the total phosphorus, the acid soluble inorganic, acid soluble organic and acid insoluble phosphorus content of the burn-injured muscle was lower than that in the uninjured muscle. The phosphorus content was found to be lowest in the burn-injured tissue during the period of 1 to 24 hours after inflicting the burn, after which time the values rose nearly to those in the uninjured muscle.

Figure 1 shows that the moisture content of the burn-injured muscle was found to be considerably greater than that of the uninjured muscle. If the increased moisture in the

FIG. I EFFECT OF BURNS ON THE MOISTURE CONTENT OF RAT MUSCLE.

BURN-INJURED MUSCLE

UNINJURED MUSCLE

FIG. II EFFECT OF BURNS ON THE PHOSPHORUS CONTENT OF RAT MUSCLE.
TOTAL PHOSPHORUS

FIG. III EFFECT OF BURNS ON THE PHOSPHORUS CONTENT OF RAT MUSCLE.
ACID-SOLUBLE INORGANIC PHOSPHORUS

FIG. IV EFFECT OF BURNS ON THE PHOSPHORUS CONTENT OF RAT MUSCLE.
ACID-SOLUBLE ORGANIC PHOSPHORUS.

FIG. V EFFECT OF BURNS ON THE PHOSPHORUS CONTENT OF RAT MUSCLE.

ACID INSOLUBLE PHOSPHORUS

BURN-INJURED MUSCLE UNINJURED MUSCLE

FIG. VI EFFECT OF BURNS ON THE PHOSPHORUS CONTENT OF RAT MUSCLE.

burn-injured muscle carried with it the normal phosphorus content of blood serum one would expect the phosphorus content of the burn-injured muscle to be greater than that of the uninjured muscle. A phosphorus content in burn-injured muscle lower than in uninjured muscle does not mean necessarily that the fluid lost to the injured area does not carry with it the normal amount of phosphorus found in serum. It does indicate, however, that phosphorus is removed from the burn-injured muscle faster than it is being carried there. It is suggested that the lower phosphorus content of burn-injured muscle may be due to the release of phosphorus-containing compounds from disintegrating burn-injured cells, the released phosphorus being carried away with fluid leaving the area.

BOOK REVIEWS.

THE TOTAL AND FREE ENERGIES OF FORMATION OF THE OXIDES OF THIRTY-TWO METALS, by Maurice deKay Thompson. 89 pages, formulae, 15 × 23 cms. New York, The Electrochemical Society, Inc., 1942.

This paper, published by The Electrochemical Society, Inc., gives equations showing the relations between temperature and total free energies of formation of the more important metallic oxides, and the details of the calculations. The data on which the calculations are based are all taken from the literature. The usual methods of determining the free energy of formation of metallic oxides including potential measurement of cells in which the oxide is formed, equilibria at high temperature of certain types, and by the third heat theorem are used in the computations. All temperatures are given on the Kelvin scale, and all energy is expressed in gram calories unless otherwise stated. Specific heat equations are from K. K. Kelly, U. S. Bureau of Mines Bulletin 371 (1934) entropies, ibid. 434 (1941), free energies of vaporation, ibid. 383 (1935), heats of fusion, ibid. 393 (1936) or from Bichowsky and Rossini's Thermochemistry, and heats of formation from Bichowsky and Rossini.

R. H. OPPERMANN.

APPLIED NUCLEAR PHYSICS, by Ernest and William L. Davidson. 249 pages, charts and diagrams, 15 × 23 cms. New York, John Wiley & Sons, 1942. Price $3.00.

Without doubt, the one scientific subject which always attracts attention is atom smashing. It fascinates those with little as well as those with greater understanding. The accompanying story of the constitution of the atom is equally interesting, more especially so now that there is still a touch of mystery about it after the passage of time since its conception as we now view it. At first these things were only considered an advance in knowledge but now they assume practical importance. From the constitution of the atom—particles of matter plus forces—come the ideas of transmutation and artificial radioactivity, which already are of service to chemists, biologists, physicians and engineers. This book has for its purpose the presentation of the essential facts and methods of artificial radioactivity and transmutation in such a way as to be of service to these workers. As such it is a translation of the language of physics into that understandable by them.

The book opens with an outline of the discoveries of transmutation and artificial radioactivity. There is shown the part the nucleus plays in determining the nature of the atom; how unstable nuclei may exist and be created; and what is the nature of their adaptation to stability. The rest of the book is a continuation and enlargement of this. First the products that can be emitted from the nuclei are discussed. Then detection and observation of these particles are described preliminary to a description of the electrostatic, voltage multiplication, the cyclotron, and induction accelerator methods of accelerating them. Transmutation

is next taken up which includes the use of the particles as well as by neutrons and gamma rays.

Radioactivity is described as the passage from an unstable nucleus to a more stable, the change being accompanied generally by the emission of a charged particle which has enough energy to ionize. The process is given quite thorough explanatory treatment. After this is a chapter on technique in artificial radioactivity which is directed to the individual interested in making actual measurements. This leads to a discussion of a collection of illustrative experiments which give to a certain extent the benefits of previous work and thereby an outlook to the near future. The application of isotopes is given consideration and lastly nuclear fission is discussed. The last chapter is devoted to the nuclear theory which gives an idea of how the nature of the nucleus itself appears to the theoretical physicist. There are a number of appendices to the book including brief references to the absorption of beta and gamma rays and energy and range relationships for fast charged particles.

This book makes available many known facts in nuclear physics to those who are advancing the subject of applied nuclear physics. It goes far in supplying an appreciation of the subject.

R. H. OPPERMANN.

HEAT, by James M. Cork. 294 pages, tables and diagrams, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1942. Price $3.50.

A knowledge of heat is of fundamental importance to everyone interested in scientific matters. It has already played a role in engineering and much can be expected in the future. This book covers the essentials of the subject adequately for practical application or for further study. It is distinctly for college grade students with proper mathematical as well as physical background. There are nine chapters. The first deals with temperature and its measurments discussing various thermometers including gas and resistance types, the thermoelectric type, and optical pyrometers. Specific heats is the next topic and this is followed by an interesting discussion on thermal expansion. A rather complete treatment is given of the transfer of heat, similarly the first law of thermodynamics. Before proceeding further with thermodynamics, a chapter on the state of matter is inserted which makes for clarity and preparation for the succeeding discussions. The last chapter is devoted to the production of high and low temperatures. This is brief and mainly descriptive. For high temperatures, there are mentioned various types of electric furnaces including conduction and induction furnaces, and for low temperatures, refrigeration by combustion, by the Linde method, and by the de-magnetization of paramagnetic substances. Appendices give practical information principally relating to thermocouples. Also in the appendix is a section giving suggested topics for experimental study. This is really an index to sections of the text which may be followed in the laboratory, although the book is not a work for use in the laboratory directly. There is a name and subject index in the back.

The book is a text in every sense of the word. Problems appear at the ends of chapters which provide some exercise. The presentation and approach is well made between the limits of a mild vigorous treatment and a not too descriptive treatment.

R. H. OPPERMANN.

SELL YOUR PHOTOGRAPHS, by Eugene Wyble. 167 pages, 14 × 20 cms. Boston, American Photographic Publishing Co., 1942. Price $2.00.

As the title implies, this book is directed to those of the great number of amateur photographers who desire to make their photographs pay expenses or actually to gain an insight into commercial work. After surveying the field for selling photographs, the book tells what equipment is needed, how to prepare and use ideas, how to create a story-telling picture, of the making of the photograph, of the treatment of the prints for market, and of the rights of the photographer and prices usually paid. The information is presented in a straightforward manner, and not through rose-colored glasses. The reader is warned that to sell his photographs he must work and be prepared for disappointments. The knowledge provided by the book saves a lot of heartaches and disillusionments and helps the photographer know the markets, an advantage that otherwise would take a long time to acquire.

R. H. OPPERMANN.

COMMUNICATION CIRCUITS, by Lawrence A. Ware and Henry R. Reed. 287 pages, diagrams, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1942. Price $3.50.

A knowledge of the fundamentals of communication circuits is now recommended to all electrical engineers, and in fact, college courses have contained such subjects for a number of years. The two large branches of electrical engineering—power and communications—are coming closer. In this book, the authors point out that communication transmission may be looked upon as a problem in transients or a problem of transmission of a great number of frequencies. Both are increasingly topics for the engineer interested in power transmission. Even more pertinent are these subjects to the power engineer when there are considered telemetering and communications over power lines.

This book is on the level of an introductory course of college grade for students in electrical engineering. It requires the usual background in electricity and magnetism and considerable mathematics. The treatment is mathematical. The opening chapter is concerned with a brief review of some of the facts connected with resistance, inductance and capacity of a line with the object in view of representing sections of a line in T and π configurations, which are the starting points for the major parts of the text. Following this there is a general discussion leading to certain transformations of the elementary T and π sections, and network theorems. The theorems taken up separately are Thévenin's, Superposition, Reciprocity, Compensation, and Maximum Power Transfer. The infinitely long line, open and short circuit lines involving methods of calculating current and voltage, the concepts of "reflection factor" and "inserted loss" are succeeding subjects.

Chapter VIII is an interesting and valuable one for electrical engineers. It compares line constants, and efficiencies of communication and power lines which assists in bringing out more clearly some of the general aspects of different kinds of lines. Next, the theory of filters is developed, beginning with a consideration of some fundamental properties of reactive networks under the heading "Constant K Filters." "M-Derived and Composite Filters" follows. Then the general problem of impedance matching is treated in an elementary manner, and some

applications of matching to high-frequency transmission by means of rectangular and cylindrical wave guides and coaxial cables is presented meeting the need for such knowledge. The last chapter of the book consists of a brief outline of a number of experiments designed to lend aid to a better understanding of various portions of the text. Reference of course is made to the different chapters. There are nine appendices covering the more advanced mathematics applicable to the text, Maxwell's equation, and other information.

This text is a vigorous passage. The authors are sympathetic to the situation of the student but do not relinquish anything of importance. The sympathy is obvious in the methods of approach and in completeness of coverage. The book is an excellent text for students with the proper prerequisites.

R. H. OPPERMANN.

PRINCIPLES OF ELECTRONICS, by Royce G. Kloeffler. 175 pages, charts and diagrams, 15 × 23 cms. New York, John Wiley & Sons, Inc., 1942. Price $2.50.

The use for knowledge of electronics is not all confined to the highly mathematical or design types. A general knowledge of theories based on some fundamentals of physics and the more simple mathematics has a wide field of practical application in addition to the possibility of being useful as a basis for more advanced studies. The present book is intended to be an introduction and as such it may be used by students as a basis for advanced study and also by those who merely need a general knowledge as for instance the older practicing engineer.

The author employs the descriptive method of presentation, leaning heavily on historic developments for his approach to the present day theories. The threads of the present conception of matter are gathered together in the early part of the book leading to the subject of electricity. Studies on gaseous conduction and electron emission are the subject fundations for two, three and multi-electrode tubes. Under the heading of special tubes later, there are described the X-ray tube, the magnetron and the electron microscope. Rectifying devices is another heading under which apparatus and equipment are described. At this point a very interesting and brief mention is made of a few physical theories and phenomena which have a close relationship with each other and a direct bearing on the discussions found elsewhere in the book. They include rays and radioactivity, spectrum of radiant energy, the quantum theory of light, and the wave theory of electrons. A good description of the theory and its applications is given of photoemission and covering photovoltaic action and photoconduction. The last chapter is devoted to electronic applications and circuits. It consists of brief information supplementing previous discussions.

The book may be used with advantage as a text for sophmore or junior college students or by practicing engineers to gain a good understanding of the subject.

R. H. OPPERMANN.

A–C CALCULATION CHARTS, by R. Lorenzen. 146 plates, illustrations, 25 × 31 cms. New York, John F. Rider Publisher, Inc., 1942. Price $7.50.

Various short cuts are used in calculations involving all kinds of engineering. The slide rule is an example in mathematics and adaptations of it in the way of

improved scales are numerous. Likewise combinations of charts, both of the sliding type and the stationary type are available. Electrical engineering has not been neglected for there are many means of reducing laborious calculations. Notable among these are the charts for determining reactances and frequencies.

The present book is one of charts covering alternating current calculations in series circuits, parallel circuits, series-parallel and mesh circuits, at frequencies from 10 cycles to 1000 megacycles. There are 72 plates used to compute reactance or impedance and another 72 plates for susceptance or admittance. These charts are arranged in groups of nine, each group having the same frequency range but with ascending values of reactance or susceptance. The charts are printed in two colors, the frequency-resistance logarithmic coordinate system is in green and the inductance-capacitance system in red. The printing job is exceptionally well done so that the charts may be used for a maximum of accuracy. Communication and power engineers will find here a tool which is a time and labor saver.

R. H. OPPERMANN.

WORKBOOK IN METEOROLOGY, by Athelstan F. Spilhaus and James E. Miller. 163 pages, charts and maps, 24 × 29 cms. New York, McGraw-Hill Book Co., Inc., 1942. Price $2.50.

This book is exactly what its title implies, a series of exercises of what is similar to a laboratory course in another field of study. The materials for working the exercises, with the exception of ordinary graph paper, are included in the book. For some exercises the requisite charts and maps are found in a pocket inside the back cover.

The exercises are divided into four groups. Group A contains nine exercises on the mean condition of the atmosphere. To give an idea of the nature of the work covered one of these was selected at random. It was number 6 and it related to rainfall of the world. First a brief explanation is given of rainfall and the means of expressing it (isohyets). Then considerations are listed in drawing isohyets and this is followed by data and procedure in preparing a report.

Other groups of exercises are on instruments and methods of observations, dynamical meteorology, and weather map and upper air analysis. There are a number of useful appendixes and a subject index in the back. For anyone interested in the subject, the book offers fascinating and practical exercises. It has valuable material for a course in meteorology.

R. H. OPPERMANN.

MAN'S PHYSICAL UNIVERSE, by Arthur Talbot Bawden. Revised edition, 832 pages, illustrations and diagrams, 16 × 24 cms. New York, The Macmillan Co., 1943. Price $4.00.

It is being said more frequently today that the future of the world should be based on the scientific attitude and its problems should be solved by means of the scientific method. Certainly it is plain that as society is now organized no one can live by and for himself alone, because his own welfare is bound up with that of the community in which he lives. But life has become more complicated with the rise of industrialism, the old communities are hardly recognizable, and the

material foundations of inherited modes of living and moral conceptions which have been cherished for generations have been destroyed. In short, physical science has wrought great changes, with accompanying problems both good and bad. The same method which has created these problems can solve them when controlled by the proper motive. This thought is underlying in the broader purpose of this book and from it springs the survey of physical phenomena.

The book is divided first into units of which there are ten, then into sections. Each unit has nine sections except the first which has six. Unit one discusses the scientific attitude and the application of the scientific method to the solution of problems and straight thinking, particularly in the social sciences. With this as a basis, the universe is taken up, describing the vast system of parts moving and changing under the influence of a flow of energy. Attention is then centered on the earth, its surface, and the atmosphere which leads to properties of matter, the knowledge of which is applied in physical processes of benefit to mankind. The study of forms of energy is another subject examined not only from the standpoint of power generation but in propagation through ether and matter, by means of vibrations. The electron theory and the effects and applications of electricity and magnetism are given adequate treatment as are the structure of the atom, chemical actions and reactions, and a number of miscellaneous physical and chemical subjects relating to man's physical welfare.

There are two outstanding features of the book. The first is its originality in method of presentation. Continuity is the keynote. Breadth of coverage is attained, rather than depth—yet it is no easy road to a wealth of knowledge. It is serious, yet simple. The second feature is its plain reference of science to the social consequences of its development, giving equal weight to the good and to the bad. In this, there is some daring shown, as such references are open to criticism from many angles. The author, however, is careful and steers a safe path.

The book is a good text for students of high school prerequisites. Its non-mathematical treatment has appeal to older people as a means of culture and understanding.

R. H. OPPERMANN.

ATOMS, ROCKS, AND GALAXIES, by John Stuart Allen, Ph.D. and Others. Revised edition, 719 pages, illustrations, 15 × 22 cms. New York, Harper & Brothers Publishers, 1942.

A knowledge of the nature of the world is a cultural basis upon which greater appreciation is had. Such knowledge is broad, covering a number of sciences sufficient to give a fair panoramic view of the universe while at the same time avoiding penetration into the sciences too far. It is often the case that this penetration results in the inability to see the forest because of the trees and also in cumbersome application to full appreciation. The Survey Course in Physical Science at Colgate University is aimed to give a definite conception of the physical world by an introduction in the fields of astronomy, chemistry, geology, and physics. The book at hand is the text for this course. It gives carefully measured weight to each subject and no attempt is made to give a fair representation of what may be expected to come later by pursuing further study.

This text is the coöperative effort of several authors. It has now been revised in accordance with longer experience in teaching, new material, and with more flexibility in its applications as to the time which may be allotted for study.

The work opens with a description of the solar system, its origin, the earth, the atmosphere and the hydrosphere. This is followed with the subject of energy including sound, heat, electrical, and light energy. What may be classed with or next to this, is the structure of matter and radiant energy, free electrons and the realm of the nucleus. Chemistry is the next subject beginning with discussions of the elements and the periodic system, chemical structure and proceeding through acids, bases, salts, ionic equilibrium, organic compounds and the production and use of chemicals. The final chapters are devoted to the sun and stars, methods of measuring the universe, and the formation of a picture of the universe and arrangement of its contents.

The presentation is in the form of a text of college freshman grade with problems for exercise at the ends of chapters as well as suggested references for supplementary reading. The book is well illustrated with diagrams and photographs and the subject index in the back adds to its value for reference purposes.

The book is good for use in the classroom and for home study by those who are to pursue a scientific career and those who just wish a general knowledge. In addition to furnishing a basis upon which an appreciation can be had of the universe, the book shows how a scientist arrives at some of his conclusions, thereby giving an appreciation of the scientific method.

R. H. OPPERMANN.

GENERAL PHYSICS FOR THE LABORATORY, by Lloyd W. Taylor, William W. Watson and Carl E. Howe. 107 pages, illustrations, charts and diagrams, 20 × 28 cms. New York, Ginn and Company, 1942. Price $2.00.

Laboratory work competently administered and well performed introduces an entirely new element in the learning process. Its primary purpose is to illustrate and clarify physical principles. It permits acquaintance with methods of measurement that is invaluable and it should impress the importance of carefulness, accuracy, and collected thinking. Any laboratory manual should have these factors in its background. The manual at hand is written in this light and merits examination by teachers of the subject.

There are 53 experiments covered in all. Generally they begin with experiments with forces and motion and proceed through work and energy, gases, waves and vibrations, light and heat. Each is given an introduction; a fairly complete outline of the theory applicable including any derivation of equations; a list of the apparatus and its arrangement, adjustment and connection; measurements; and calculations. Considerable space is devoted to an appendix which contains much helpful information in the form of tables. Also here in the back are record sheets for use in each experiment, and a subject index.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Man's Physical Universe, by Arthur Talbot Bawden. Revised Edition. 832 pages, illustrations and diagrams, 16 × 24 cms. New York, The Macmillan Company, 1943. Price $4.00.

Noxious Gases and the Principles of Respiration Influencing Their Action, by Yandell Henderson and Howard W. Haggard. 294 pages, charts and diagrams, 15 × 23 cms. New York, Reinhold Publishing Corp., 1943. Price $3.50.

Engineering Mechanics, by Glen N. Cox, Ph.D. 301 pages, charts and diagrams, 16 × 23 cms. New York, D. Van Nostrand Company, Inc., 1943. Price $3.00.

College Physics, by Henry A. Perkins, Sc.D. Revised Edition. 802 pages, illustrations, 16 × 23 cms. New York, Prentice-Hall, Inc., 1943. Price $4.50.

Fire Protection Engineering, by the National Fire Protection Association. 196 pages, illustrations, charts, diagrams, 16 × 23 cms. Boston, National Fire Protection Association, 1943. Price $2.00.

Metallography, by Cecil H. Desch, D.Sc., Ph.D., F.R.S. 408 pages, illustrations, 14 × 22 cms. New York, Longmans, Green and Co., Inc., 1942. Price $8.00.

Nicholas Copernicus 1543–1943, by Stephen P. Mizwa, A.M., LL.D. 88 pages, illustrations, 18 × 25 cms. New York, The Kosciuszko Foundation, 1943.

CURRENT TOPICS.

Diamond Dust Is Recovered For "Hardest" War Industry Jobs. Diamonds are being pulverized to perform one of war industry's "hardest" jobs, according to C. B. SHOPMYER of General Electric's Schenectady works laboratory. Soft and white as face powder in appearance, diamond dust is being used to polish tungsten carbide dies to a degree of smoothness which eliminates much friction. Diamond dust is the best substance for polishing tungsten carbide, one of the hardest compounds yet devised by science. Dies made of this compound are used in drawing larger size copper wire, an important element in all types of electric equipment. Diamond dust may be used over and over again, but recovery is a problem. During polishing, the dust falls into a receptacle with oil, tungsten carbide particles and bits of cloth. The recovery process ordinarily requires large amounts of acids which destroy everything but the diamond dust, but Mr. Shopmyer recently devised a greatly simplified method. The new method requires only small amounts of chemicals and the process can be completed by technicians in half the time. Like other organizations which operate wire drawing machines, General Electric buys diamonds in dies. A tiny hole—from .0025 to .0641 inch in diameter—is already drilled in the diamond and the diamond embedded in the center of a metal die shaped like a thick coin. Several dies, each having a slightly smaller hole in the center, are placed in each automatic wire-drawing machine. After several thousand pounds of wire have been drawn the diamonds show signs of wear. They are then re-drilled to a larger size for re-use. Like a librarian checking out a new book, the die maker then stamps the measurement of the new size on the die. After several re-borings, however, the diameter of the diamond becomes too large for drawing small wire. Then the die may be dissolved chemically and the diamond removed. The diamond is crushed into dust, which in turn is sifted through an extremely fine sieve. Sifting guarantees uniformity of diamond dust particles. Sifted and graded, the dust is ready for polishing tungsten carbide wire-drawing dies. These dies are used in drawing larger size wire and even rods—from .0641 to seven-eighths of an inch in diameter. By means of Mr. Shopmyer's method, the dust can then be recovered and re-used for the same purpose.

R. H. O.

Plastic Pipe and Tubing One Solution of Metal Shortage Problem.—(*The Petroleum Engineer*, Vol. 14, No. 1.) Keeping the rate of production at a maximum level in the oil industry means extra wear and tear on equipment such as small pipe and tubing. One answer to the stringent metal situation now facing the oil industry is saran plastic pipe a product of the Dow Chemical Co. It has a wide variety of applications and is manufactured to fit and to fill many needs. The pipe is tough, durable, flexible, and non-scaling. Other unusual properties are its ability to resist the solvent and corrosive action of oils, soaps, chemicals, and moisture. Production of the pipe by a modified extrusion process assures a smooth, round material having dimensions identical to those of extra strong iron pipe. Sharp standard pipe dies can be used to thread saran pipe, an operation that exactly parallels cutting of standard pipe threads on metallic pipe, and renders practicable its installation with either metallic or saran fittings. An important factor in shipping, general handling, and suspension is saran's weight—less than one-quarter that of iron. Welding operations with the pipe are simple and can be accomplished in less than one minute; two lengths of pipe are placed on a heated surface (temperature 350° to 400° F.) and held long enough to form a small amount of molten material. The bead or molten material is visible at the outside surfaces of the two pieces. Then the two ends are pressed together and allowed to cool for a few seconds. Within 24 hours the welded joint has strength equal to any other part of the pipe. Direct-heating methods are ideal for welding in the field. The pipe lends itself, under adverse conditions, to this method, for it can be easily welded with use of gas flame or torch-heated unit, against which two pieces of pipe are placed. The general rules of heated plate welding should be observed and care must be taken not to overheat the material, for this will substantially weaken the joint. Tubing of this material is tough but flexible, and withstands freezing and continuous heat up to 170° F., and it is non-corrosive and non-scaling.

R. H. O.

Speleology.—(*Industrial Bulletin of Arthur D. Little, Inc.* No. 183.) In prehistoric times caves provided shelter for man from the elements and wild animals, and today the caves of Malta and of Chungking are shelters against almost continuous bombing. Spectacular caves noted for beauty and strangeness attract crowds of sightseers. Cave study has become a science named speleology, from the Greek word for cave spelaion, and speleologists study the history and peculiarities of curious caves. The Bermuda caves were

hollowed from soft rock by washing and pounding of the sea, but most have been dissolved from limestone by rainwater and carbon dioxide, usually with the help of a stream carrying away loose dirt. While limestone is resistant to plain water, it dissolves in carbonated water, and thus wears away. If later the carbon dioxide escapes from the water holding the limestone in solution, the calcium carbonate is deposited and may, by the heat and pressure of metamorphosis, become a smooth, more or less transparent, crystalline form known as marble. These processes account for the slow erosion of great masses of limestone rock to make caves and of deposition, as stalactites, or hanging "icicles," and stalagmites that come up from the floor to meet them, often forming solid columns. Some are fluted and folded into fantastic shapes and may be tinted with iron and other coloring substances. The famous Luray Caverns in Virginia apparently were filled with an acid red mud for a long period after they were formed, this mud acting on the marble to leave unusual and colorful effects when the mud had washed out. Some have rivers running through them at great depths, with fish blind from long residence in the dark. These cave rivers sometimes disappear and then reappear miles away, perhaps in another cave. Carbon dioxide gas in caves has caused peculiar phenomena, as in the Grotto of the Dogs, where a dog becomes suffocated by the concentration of carbon dioxide near the floor while his master may walk unharmed above it, perhaps ignorant of its existence. Emanations of carbon dioxide from a cave made the Delphian oracle sufficiently groggy to give the oracle's sayings prophetical reputation.

R. H. O.

Music While You Work.—ELINOR F. SYLVESTER in *Domestic Commerce*, Vol. 30, No. 20, states that the power of music has long been recognized, but only in recent years has it become an "industrial power." The theory that music could be utilized to stimulate production, now being followed in many manufacturing plants in the United States, was introduced in factories in Great Britain in June 1940 and has successfully passed the experimental stage. Studies made by the Ministry of Labor and National Service and by the British Broadcasting Corporation all indicate that while it is almost impossible to offer comprehensive statistics to prove that music is responsible for increased production, there is not the slightest doubt that this is the case. The British Broadcasting Corporation states that its investigations show music aids production by boosting the tired worker, acting as a mental tonic, relieving boredom, increasing happiness, improving health, minimizing conversation, relieving nervous strain, and cutting down absenteeism. It is

generally believed that not more than 2½ hours of music during a regular working day are desirable; the effectiveness is lost if too much music is provided. Extra music periods on days when the weather is bad, or after air raids, have also been found helpful in giving the workers' spirits a "lift." Workers, especially women, performing repetitious tasks apparently benefit most from the musical programs. Skilled workers also like them, but are more critical of the type of music and of the manner of presentation. The programs seem to be of least value to office workers and executives. The mechanical problems involved in presenting the music should be given careful consideration. Poor equipment or faulty installation can make the programs a liability rather than an asset. Some strong advocates of music for workers claim that it lessens the danger of accidents; but no conclusive evidence has yet been presented to substantiate this. It is quite possible, however, that by relieving boredom and nervous tension, music keeps employees more alert and thus does decrease accidents resulting from carelessness.

R. H. O.

Glass Jewels Speed Instrument Manufacture. Mass production of a glass substitute for war-scarce sapphire jewels has spurred the manufacture of millions of delicate indicating instruments used in the field radio sets, mobile power stations, searchlights, and radio control equipment aboard planes, ships, and tanks, according to J. H. Goss and F. K. McCUNE, engineers at one of General Electric's New England plants. The moving parts of such instruments are of watch size and delicacy, each requiring two cup-shaped jewels comparable in size to the head of a pin. Such jewels are known as "Vee" jewels, for in the flat top of each one is a V-shaped depression in which a cone-shaped steel pivot rotates. The radius of each depression measures from three to four thousandths of an inch. Before the war, American demand for "Vee" jewels was supplied chiefly by Swiss craftsmen who, with such precision tools as miniature lathes, cut them from natural or synthetic sapphires. The uncertainty of wartime shipping and the absence of mass production methods, however, rendered the Swiss supply of sapphire jewels hopelessly inadequate. Intensive General Electric laboratory experimentation as a result developed the glass "Vee" jewel as a substitute. By this development a special type of glass is fused and formed into miniature jewels by a secret mass production process which can yield millions of glass jewels yearly. By means of an improvement recently developed and now being installed "Vee" jewel forming machinery soon will be clicking out these jewels on a completely automatic basis. General Electric began in 1929 to

experiment with a jewel formed from a drop of fused-hard glass, on the theory that glass could be made into almost any desired shape. Control of the shape, however, proved difficult. After the outbreak of the war in 1939 General Electric reviewed its previous experiments with glass jewels and began exhaustive tests of improved glass formulas which had been developed in the intervening years. When a satisfactory compound had been selected laboratory engineers set to work designing new equipment which would make mass production possible.

R. H. O.

Use of Mixtures of Oil and Coal in Boiler Furnaces.—W. C. SCHROEDER (*Mechanical Engineering*, Vol. 64, No. 11). The shortage of fuel oil on the eastern seaboard has revived interest in the mixing of oil with coal to produce a fuel suitable for use in oil-burning industrial furnaces without material alteration in equipment. The preparation of stable oil-coal mixtures was intensively studied in 1917 and 1918 in connection with the work of the Submarine Defense Association, but there has been relatively little interest since that time, probably because of the low cost of fuel oil in this country. In Great Britain, on the other hand, while interest has been spasmodic, it has never disappeared entirely. Mr. Schroeder, who is Assistant Chief, Fuels and Explosives Service, Bureau of Mines, Washington D. C., considers the use of oil-coal mixtures for furnaces under stationary boilers and gives a resume of the work which has been done to date. The preparation of oil-coal fuel can be approached from three viewpoints: (1) to make a mixture sufficiently stable so that no settling will occur under any normal condition; (2) to provide stirrers in the storage and transportation equipment which can be run periodically to mix the coal back into the oil; and (3) to mix the oil and coal at the plant where they are to be used and provide agitators or recirculating equipment on the fuel tanks which will prevent settling. This latter procedure would make it necessary to pulverize coal at the plant or to ship pulverized coal to the plant. Since coal in this form may be explosive, it would require careful handling until the mixing with oil was completed. The possibilities inherent in the second and third suggestions should not be overlooked with reference to making a composite fuel available quickly, since they alleviate some of the difficulty in producing a mixture which is stable over a long period. Mention is made of burning demonstrations with coal-oil fuel which have apparently been quite successful. There are three criticisms of the major portion of this work, according to Mr. Schroeder: The tests have usually been conducted on small boilers; the test time

has been too short to be sure of the ultimate result; and there has been a distinct failure to observe or make public the details of the tests. These difficulties must be remedied to secure any widespread use of colloidal fuel.

R. H. O.

Application and Control of Capacitors on Multi-Phase Loads.—W. A. SMILEY of the Electrical Department of the Bethlehem Steel Company has presented a paper before the Philadelphia District Section of the Association of Iron and Steel Engineers that will be of interest to many electrical power engineers. The paper appears in *Iron and Steel Engineer*, Vol. XIX, No. X. It relates to the power supply of a steel wire and cable manufacturing plant. The incoming service was 11000 volts, 3 phase, 60 cycles. The energy was converted by two 750 KVA transformers, Scott connected to two phase 440 volts and load was supplied mainly by 4 conductors. Existing power factor was 60% lagging resulting in hot cables and oil switches. The plant was operating at 92% load factor. The problem was to change from 2 phase to 3 phase without shut down and to provide efficient and economical power which included continuance of some over-motored conditions, they being necessary on account of the starting of high inertia loads. To gradually convert the plant to 3 phase, additional transformers were used. An open delta connection was used on the primary with the addition of a transformer primary connection vertically from the apex of the delta to and through the midpoint of the horizontal phase. Feeders were connected to the end points of the open delta. Secondaries were similarly connected and three leads were taken from the end points of the open delta and one from the bottom of the vertical winding below the horizontal phase. There is no tie-in of the vertical with the horizontal phases. Vectorially this looks like the conventional 3 phase star diagram, added to which is a 90 degree leg. This combination gives both 2 and 3 phases according to the use of the four conductors and presents a very interesting study. It permits motor rewinding for 3 phase while replaced with 2 phase machines and the immediate change, and also allows the use of present 4 conductor installation. Power factor correcting is obtained by single phase shunt capacitors at load centers operated by a kilovar relay with a timing relay which imposes a delay of 25 seconds before a capacitor is switched. During this period the need for the change must be continuous and without interruption. Correction was made to about 99 per cent. power factor, taking full advantage of all the benefits including line losses, and the penalty clause in the power company rate.

R. H. O.

Electric Heater Sets Turbine Bolts Tight.—E. F. MILLER of the Westinghouse Electric and Manufacturing Company, South Philadelphia Works, states in *Electrical World*, Vol. 118, No. 20, that bending and torsional stresses in turbine-casing bolts should be reduced to a minimum. These are particularly bad for high temperature bolting where ductility and shock resistance may have been sacrificed in some degree for desirable creep or relaxation properties. But in addition to proper heat treatment of a bolt of proper material, there is the opportunity to use heat in conjunction with the tightening of the nut to avoid the undesirable bending, torsional, and shock strains that arise from wrench and hammer methods of tightening. Preheating in a furnace, by torch or by external resistors, necessitates haste in placing and tightening the bolts and results in unpredictable stresses. A much preferable procedure is based on internal heating of the bolt which involves provision of a hole through it to accommodate the means of heating. Experience has shown the electrical heater more precise and dependable than hot air, torch flame, or superheated steam. But even in applying electric heat it is important to have high output for quick application of the heat to the bolt with minimum heating of flanges and surrounding parts. Rods of carbon or resistance alloys served by heavy current low voltage transformers have been used with good success, but burning of the bolt often results. A new procedure employs a slender cylindrical heater of high output for operation on standard voltages, having a helically wound resistance element that interposes no thermal insulation between it and the inner wall of the bolt. The coil is wound in a deep helical groove in a tubular ceramic core. Flat-topped bands between the grooves prevent shortcircuiting of turns by contact with the bolt. The heaters are designed for use in hole sizes of one-fourth the normal bolt diameter and are available in outputs of 0.9 to 18 kw. to function with $1\frac{1}{2}$ to 6 in. bolts, in the latter size up to 15 ft. length. Satisfactory heating rate is obtained with a capacity of 50 watts per inch of bolt diameter per inch of length. With such input the heating is completed in about five minutes for each inch of diameter. Thus a 3 in. bolt requires about fifteen minutes, the variations depending on the amount of tightening desired and the physical proportions of the flange. Micrometer measurements of the bolt length (hole bottom to nut end) before heating and after cooling provide a basis for determining whether the stress under the set-up condition conforms to the desired value.

R. H. O.

Spot Conditioning Used to Speed War Production.—(*Refrigerating Engineering*, Vol. 44, No. 5.) With the tightening of critical materials, many new plants are, of necessity, air conditioning only vital areas instead of the entire plant. For example, an airplane plant recently erected a duplicate factory except for the 6000 h.p. air conditioning plant. Instead, the plant uses several small scattered air conditioning units for essential production spots. "Spot" air conditioning is increasingly used for such things as special manufacturing processes, laboratories, testing rooms, and store rooms for instruments and perishable supplies. Often individual self-contained units are applied up to 25 tons. For higher capacities a central system may be required. Spot conditioning of special manufacturing areas is essential to much war production. A typical case is in holding constant temperature and humidity while cutting marine propulsion gears. At one point, each of the precision hobbing machines are in separate insulated rooms and air conditioned by 25 units ranging from $2\frac{1}{2}$ to 5 tons. Holding constant temperature throughout the continuous 17 day gear cutting period maintains the close tolerances. Similarly, low relative humidity prevents condensation on the gear and tools. From two to four men work in each room and outside air is introduced, mixed with room air and brought through the air handling unit to provide a proper working atmosphere. The internal design conditions are 75° F. dry bulb, held within ± 1° F., and the relative humidity is held at approximately 60 per cent. The rooms vary from 12 × 16 ft. high to 38 ft. × 32 ft. × 18 ft. high and are of double steel construction with insulation between the walls. Each air conditioning unit has a heating and cooling coil; 13 evaporative condensers are used for condensing purposes. This is but one of the hundreds of industrial processes where this "spot" air conditioning serves war production. It is flexible, easy to install and adaptable to practically any process where a control of temperature and relative humidity is required.

R. H. O.